

5. External lightning protection

5.1 Air-termination systems

The function of the air-termination systems of a lightning protection system is to prevent direct lightning strikes from damaging the volume to be protected. They must be designed to prevent uncontrolled lightning strikes to the structure to be protected.

By correct dimensioning of the air-termination systems, the effects of a lightning strike to a structure can be reduced in a controlled way.

Air-termination systems can consist of the following components and can be combined with each other as required:

- ⇒ Rods
- ⇒ Spanned wires and cables
- ⇒ Intermeshed conductors

When determining the siting of the air-termination systems of the lightning protection system, special attention must be paid to the protection of corners and edges of the structure to be protected. This applies particularly to air-termination systems on the surfaces of roofs and the upper parts of facades. Most importantly, air-termination systems must be mounted at corners and edges.

Three methods can be used to determine the arrangement and the siting of the air-termination systems (**Figure 5.1.1**):

- ⇒ Rolling sphere method
- ⇒ Mesh method
- ⇒ Protective angle method

The rolling sphere method is the universal method of design particularly recommended for geometrically complicated applications.

The three different methods are described below.

5.1.1 Designing methods and types of air-termination systems

The rolling sphere method – “geometric-electrical model”

For lightning flashes to earth, a downward leader grows step-by-step in a series of jerks from the cloud towards the earth. When the leader has got close to the earth within a few tens, to a few hundreds of metres, the electrical insulating strength of the air near the ground is exceeded. A further “leader” discharge similar to the downward leader begins to grow towards the head of the downward leader: the upward leader. This defines the

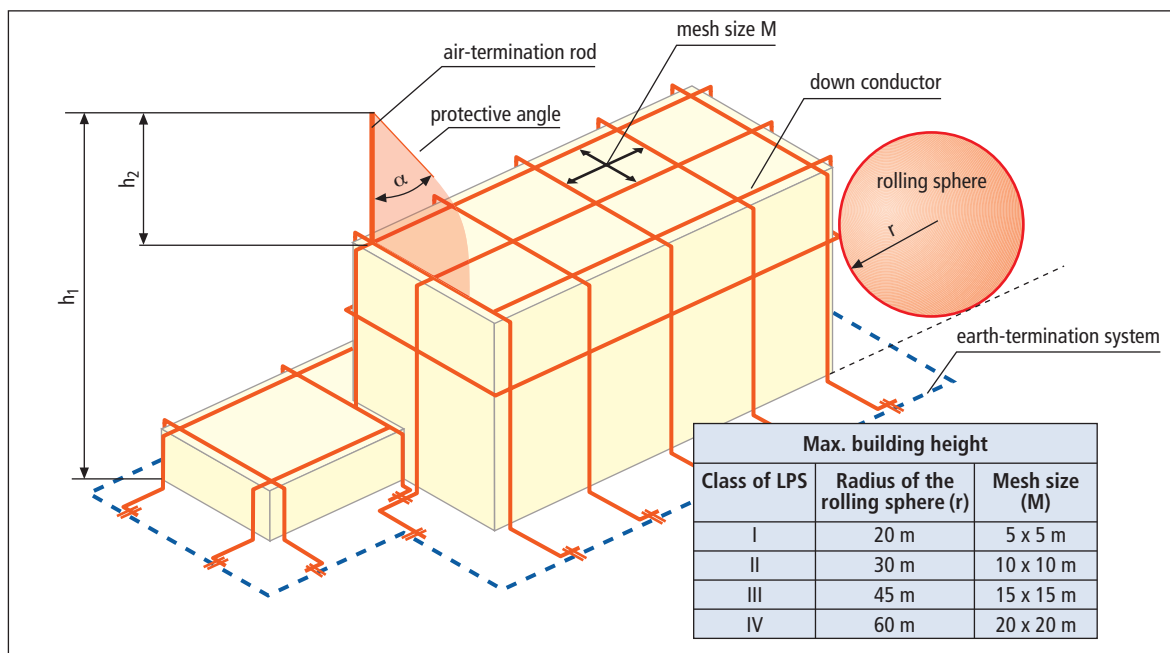


Fig. 5.1.1 Method for designing of air-termination systems for high buildings

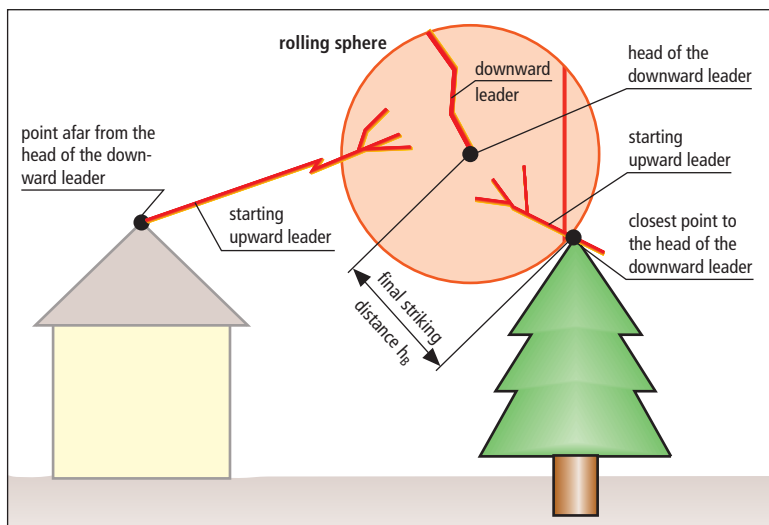


Fig. 5.1.1.1 Starting upward leader defining the point of strike



Fig. 5.1.1.2 Model of a rolling sphere
Ref: Prof. Dr. A. Kern, Aachen

point of strike of the lightning strike (Figure 5.1.1.1).

The starting point of the upward leader and hence the subsequent point of strike is determined mainly by the head of the downward leader. The head of the downward leader can only approach the earth within a certain distance. This distance is defined by the continuously increasing electrical field strength of the ground as the head of the downward leader approaches. The smallest distance between the head of the downward leader and the starting point of the upward leader is called the final striking distance h_B (corresponds to the radius of the rolling sphere).

Immediately after the electrical insulating strength is exceeded at one point, the upward leader which leads to the final strike and manages to cross the final striking distance, is formed. Observations of the protective effect of guard wires and pylons were used as the basis for the so-called “geometric-electrical model”.

This is based on the hypothesis that the head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.

The point of strike is then determined by the object closest to the head of the downward leader. The upward leader starting from this point “forces its way through” (Figure 5.1.1.2).

Classification of the lightning protection system and radius of the rolling sphere

As a first approximation, a proportionality exists between the peak value of the lightning current and the electrical charge stored in the downward leader. Furthermore, the electrical field strength of the ground as the downward leader approaches is also linearly dependent on the charge stored in the downward leader, to a first approximation. Thus there is a proportionality between the peak value I of the lightning current and the final striking distance h_B (= radius of the rolling sphere):

$$r = 10 \cdot I^{0.65}$$

r in m

I in kA

The protection of structures against lightning is described in IEC 62305-1 (EN 62305-1). Among other things, this standard defines the classification of the individual lightning protection system and stipulates the resulting lightning protection measures.

It differentiates between four classes of lightning protection system. A Class I lightning protection system provides the most protection and a Class IV, by comparison, the least. The interception effec-

Lightning protection level LPL	Probabilities for the limit values of the lightning current parameters		Radius of the rolling sphere (final striking distance h_b) r in m	Min. peak value of current I in kA
	< Max. values acc. to Table 5 IEC 62305-1 (EN 62305-1)	> Min. values acc. to Table 6 IEC 62305-1 (EN 62305-1)		
IV	0.84	0.97	60	16
III	0.91	0.97	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

Table 5.1.1.1 Relations between lightning protection level, interception criterion E_i , final striking distance h_b and min. peak value of current I
Ref.: Table 5, 6 and 7 of IEC 62305-1 (EN 62305-1)

tiveness E_i of the air-termination systems is concomitant with the class of lightning protection system, i.e. which percentage of the prospective lightning strikes is safely controlled by the air-termination systems. From this results the final striking distance and hence the radius of the “rolling sphere”. The correlations between class of lightning protection system, interception effectiveness E_i of the air-termination systems, final striking distance / radius of the “rolling sphere” and current peak value are shown in **Table 5.1.1.1**.

Taking as a basis the hypothesis of the “geometric-electrical model” that the head of the downward leader approaches the objects on the earth in an arbitrary way, unaffected by anything, until it reaches the final striking distance, a general method can be derived which allows the volume to be protected of any arrangement to be inspected. Carrying out the rolling sphere method requires a scale model (e.g. on a scale of 1:100) of the building / structure to be protected, which includes the external contours and, where applicable, the air-termination systems. Depending on the location of the object under investigation, it is also necessary to include the surrounding structures and objects, since these could act as “natural protective measures” for the object under examination.

Furthermore, a true-to-scale sphere is required according to the class of lightning protection system with a radius corresponding to the final striking distance (depending on the class of lightning protection system, the radius r of the “rolling sphere” must correspond true-to-scale to the radii 20, 30, 45 or 60 m). The centre of the “rolling sphere” used corresponds to the head of the downward leader towards which the respective upward leaders will approach.

The “rolling sphere” is now rolled around the object under examination and the contact points representing potential points of strike are marked in each case. The “rolling sphere” is then rolled over the object in all directions. All contact points are marked again. All potential points of strike are thus shown on the model; it is also possible to determine the areas which can be hit by lateral strikes. The naturally protected zones resulting from the geometry of the object to be protected and its surroundings can also be clearly seen. Air-termination conductors are not required at these points (**Figure 5.1.1.3**).

It must be borne in mind, however, that lightning footprints have also been found on steeples in places not directly touched as the “rolling sphere” rolled over. This is traced to the fact that, among other things, in the event of multiple lightning flashes, the base of the lightning flash moves because of the wind conditions. Consequently, an area of approx. one metre can come up around the

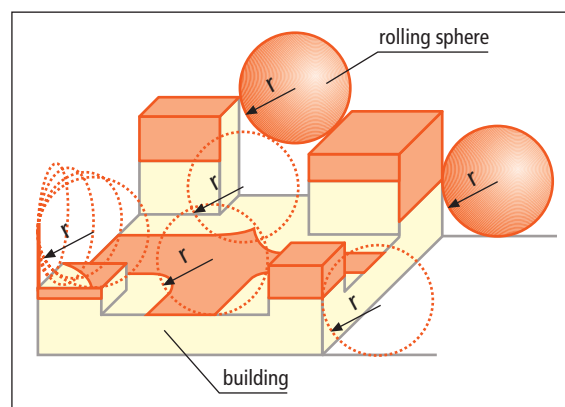


Fig. 5.1.1.3 Schematic application of the “rolling sphere” method at a building with considerably structured surface

point of strike determined where lightning strikes can also occur.

Example 1: New administration building in Munich

During the design phase of the new administration building, the complex geometry led to the decision to use the rolling sphere method to identify the areas threatened by lightning strikes.

This was possible because an architectural model of the new building was available on a scale of 1:100.

It was determined that a lightning protection system Class I was required, i.e. the radius of the rolling sphere in the model was 20 cm (**Figure 5.1.1.4**).

The points where the “rolling sphere” touches parts of the building, can be hit by a direct lightning strike with a corresponding minimum current peak value of 3 kA (**Figure 5.1.1.5**). Consequently, these points required adequate air-termination systems. If, in addition, electrical installations were localised at these points or in their immediate vicinity (e.g. on the roof of the building), additional air-termination measures were realised there.

The application of the rolling sphere method meant that air-termination systems were not installed where protection was not required. On the other hand, locations in need of more protection could be equipped accordingly, where necessary (**Figure 5.1.1.5**).

Example 2: Aachen Cathedral

The cathedral stands in the midst of the old town of Aachen surrounded by several high buildings. Adjacent to the cathedral there is a scale model (1:100) whose purpose is to make it easier for visitors to understand the geometry of the building. The buildings surrounding the Aachen Cathedral provide a partial natural protection against lightning strikes.

Therefore, and to demonstrate the effectiveness of lightning protection measures, models of the most important elements of the surrounding buildings were made according to the same scale (1:100) (**Figure 5.1.1.6**).

Figure 5.1.1.6 also shows “rolling spheres” for lightning protection systems Class II and III (i.e. with radii of 30 cm and 45 cm) on the model.



Fig. 5.1.1.4 Construction of a new administration building: Model with “rolling sphere” acc. to lightning protection system Type I
Ref.: WBG Wiesinger



Fig. 5.1.1.5 Construction of a DAS administration building: Top view (excerpt) on the zones threatened by lightning strikes for lightning protection system Class I
Ref.: WBG Wiesinger



Fig. 5.1.1.6 Aachen Cathedral: Model with environment and “rolling spheres” for lightning protection systems Class II and III
Ref.: Prof. Dr. A. Kern, Aachen

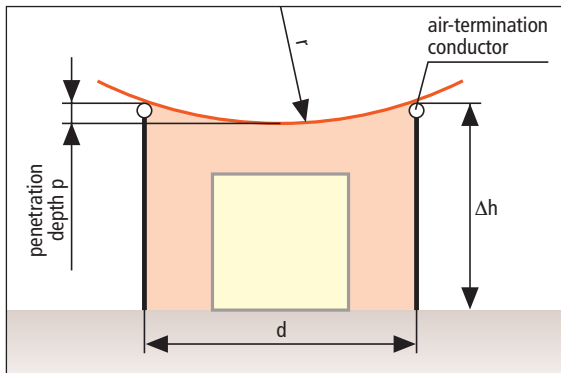


Fig. 5.1.1.7 Penetration depth p of the rolling sphere

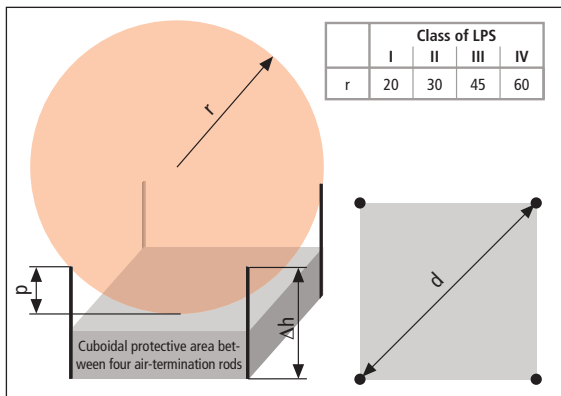


Fig. 5.1.1.8 Air-termination system for installations mounted on the roof with their protective area

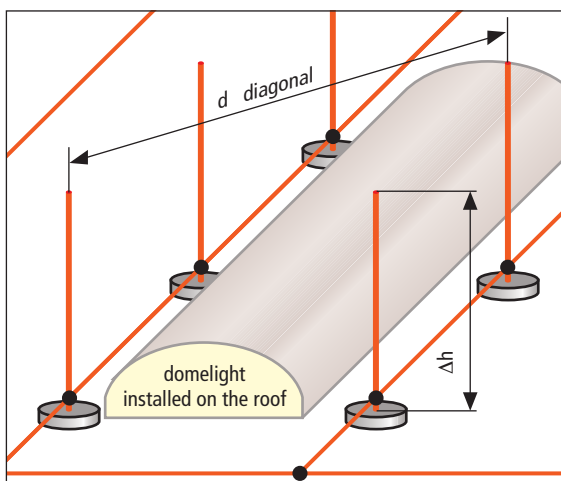


Fig. 5.1.1.9 Calculation Δh for several air-termination rods according to rolling sphere method

The aim here was to demonstrate the increasing requirements on the air-termination systems as the radius of the rolling sphere decreases, i.e. which areas of Aachen Cathedral had additionally to be considered at risk of being hit by lightning strikes, if a lightning protection system Class II with a higher degree of protection was used.

The “rolling sphere” with the smaller radius (according to a class of lightning protection system with a higher lightning protection level) naturally touches also the model at all points already touched by the “rolling sphere” with the larger radius. Thus, it is only necessary to determine the additional contact points.

As demonstrated, when dimensioning the air-termination system for a structure, or a structure mounted on the roof, the sag of the rolling sphere is decisive.

The following formula can be used to calculate the penetration depth p of the rolling sphere when the rolling sphere rolls “on rails”, for example. This can be achieved by using two spanned wires, for example.

$$p = r - \left[r^2 - (d/2)^2 \right]^{1/2}$$

r Radius of the rolling sphere

d Distance between two air-termination rods or two parallel air-termination conductors

Figure 5.1.1.7 illustrates this consideration.

Air-termination rods are frequently used to protect the surface of a roof, or installations mounted on the roof, against a direct lightning strike. The square arrangement of the air-termination rods, over which no cable is normally spanned, means that the sphere does not “roll on rails” but “sits deeper” instead, thus increasing the penetration depth of the sphere (**Figure 5.1.1.8**).

The height of the air-termination rods Δh should always be greater than the value of the penetration depth p determined, and hence greater than the sag of the rolling sphere. This additional height of the air-termination rod ensures that the rolling sphere does not touch the structure to be protected.

d	Sag of the rolling sphere [m] (rounded up)			
Distance between air-termination rods [m]	Class of LPS with rolling sphere radius in meters			
	I (20 m)	II (30 m)	III (45 m)	IV (60 m)
2	0.03	0.02	0.01	0.01
4	0.10	0.07	0.04	0.03
6	0.23	0.15	0.10	0.08
8	0.40	0.27	0.18	0.13
10	0.64	0.42	0.28	0.21
12	0.92	0.61	0.40	0.30
14	1.27	0.83	0.55	0.41
16	1.67	1.09	0.72	0.54
18	2.14	1.38	0.91	0.68
20	2.68	1.72	1.13	0.84
23	3.64	2.29	1.49	1.11
26	4.80	2.96	1.92	1.43
29	6.23	3.74	2.40	1.78
32	8.00	4.62	2.94	2.17
35	10.32	5.63	3.54	2.61

Table 5.1.1.2 Sag of the rolling sphere over two air-termination rods or two parallel air-termination conductors

Another way of determining the height of the air-termination rods is using **Table 5.1.1.2**. The penetration depth of the rolling sphere is governed by the largest distance of the air-termination rods from each other. Using the greatest distance, the penetration depth p (sag) can be taken from the table. The air-termination rods must be dimensioned according to the height of the structures mounted on the roof (in relation to the location of the air-termination rod) and also the penetration depth (**Figure 5.1.1.9**).

If, for example, a total height of an air-termination rod of 1.15 m is either calculated or obtained from the table, an air-termination rod with a standard length of 1.5 m is normally used.

Mesh method

A “meshed” air-termination system can be used universally regardless of the height of the structure and shape of the roof. A reticulated air-termination network with a mesh size according to the class of lightning protection system is arranged on the roofing (**Table 5.1.1.3**).

To simplify matters, the sag of the rolling sphere is assumed to be zero for a meshed air-termination system.

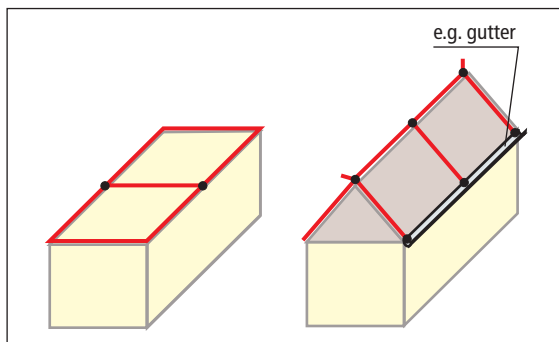


Fig. 5.1.1.10 Meshed air-termination system

By using the ridge and the outer edges of the structure, as well as the metal natural parts of the structure serving as an air-termination system, the individual cells can be sited as desired.

The air-termination conductors on the outer edges of the structure must be laid as close to the edges as possible.

A metal attic can serve as an air-termination conductor and / or a down-conductor system if the required minimum dimensions for natural components of the air-termination system are complied with (**Figure 5.1.1.10**).

Protective angle method

The protective angle method is derived from the electric-geometrical lightning model. The protective angle is determined by the radius of the rolling sphere. The comparable protective angle with the radius of the rolling sphere is given when a slope intersects the rolling sphere in such a way that the resulting areas have the same size (**Figure 5.1.1.11**).

This method must be used for structures with symmetrical dimensions (e.g. steep roof) or roof-mounted structures (e.g. antennas, ventilation pipes).

The protective angle depends on the class of lightning protection system and the height of the air-

Class of LPS	Mesh size
I	5 x 5 m
II	10 x 10 m
III	15 x 15 m
IV	20 x 20 m

Table 5.1.1.3 Mesh size

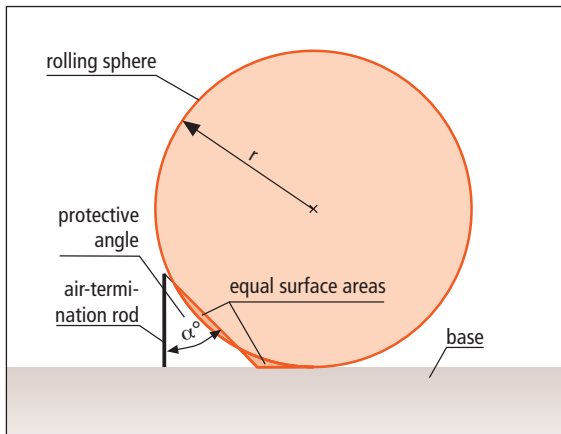


Fig. 5.1.1.11 Protective angle and comparable radius of the rolling sphere

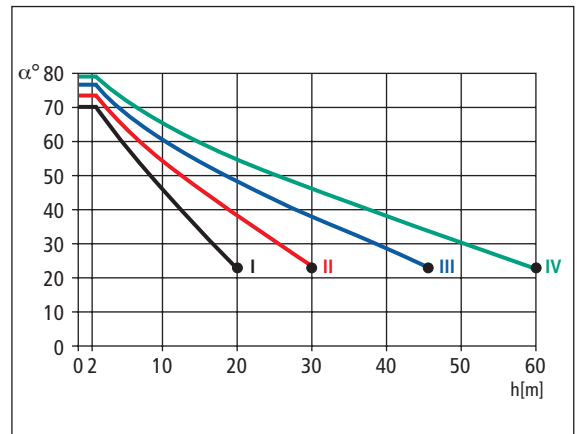


Fig. 5.1.1.12 Protective angle α as a function of height h depending on the class of lightning protection system

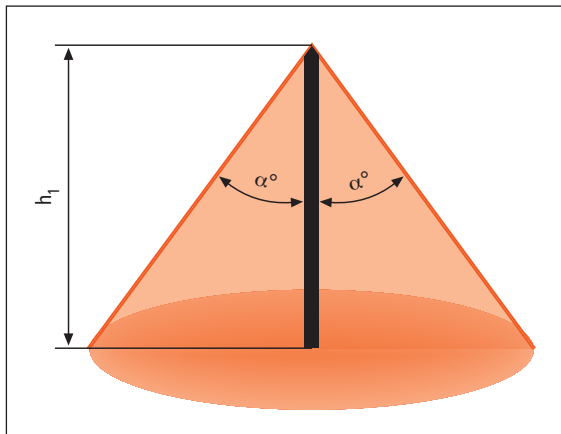


Fig. 5.1.1.13 Cone-shaped protection zone

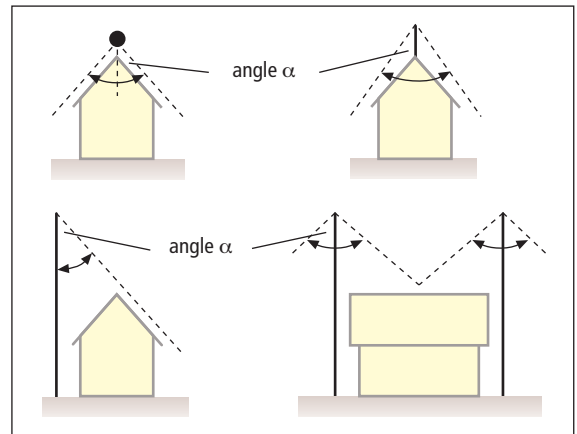


Fig. 5.1.1.14 Example of air-termination systems with protective angle α

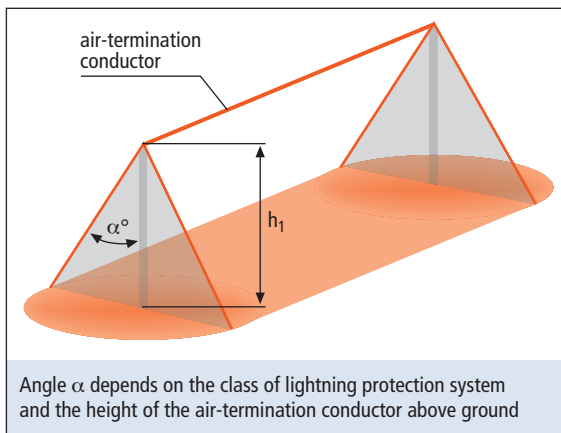


Fig. 5.1.1.15 Area protected by an air-termination conductor

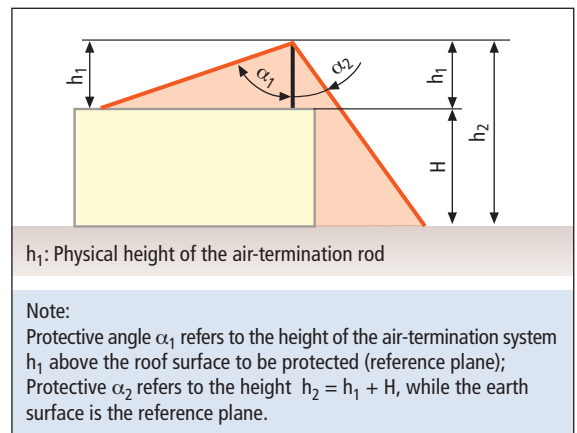


Fig. 5.1.1.16 External lightning protection system, volume protected by a vertical air-termination rod

Height of the air-termination rod h in m	Class of LPS I		Class of LPS II		Class of LPS III		Class of LPS IV	
	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m
1	71	2.90	74	3.49	77	4.33	79	5.14
2	71	5.81	74	6.97	77	8.66	79	10.29
3	66	6.74	71	8.71	74	10.46	76	12.03
4	62	7.52	68	9.90	72	12.31	74	13.95
5	59	8.32	65	10.72	70	13.74	72	15.39
6	56	8.90	62	11.28	68	14.85	71	17.43
7	53	9.29	60	12.12	66	15.72	69	18.24
8	50	9.53	58	12.80	64	16.40	68	19.80
9	48	10.00	56	13.34	62	16.93	66	20.21
10	45	10.00	54	13.76	61	18.04	65	21.45
11	43	10.26	52	14.08	59	18.31	64	22.55
12	40	10.07	50	14.30	58	19.20	62	22.57
13	38	10.16	49	14.95	57	20.02	61	23.45
14	36	10.17	47	15.01	55	19.99	60	24.25
15	34	10.12	45	15.00	54	20.65	59	24.96
16	32	10.00	44	15.45	53	21.23	58	25.61
17	30	9.81	42	15.31	51	20.99	57	26.18
18	27	9.17	40	15.10	50	21.45	56	26.69
19	25	8.86	39	15.39	49	21.86	55	27.13
20	23	8.49	37	15.07	48	22.21	54	27.53
21			36	15.26	47	22.52	53	27.87
22			35	15.40	46	22.78	52	28.16
23			36	16.71	47	24.66	53	30.52
24			32	15.00	44	23.18	50	28.60
25			30	14.43	43	23.31	49	28.76
26			29	14.41	41	22.60	49	29.91
27			27	13.76	40	22.66	48	29.99
28			26	13.66	39	22.67	47	30.03
29			25	13.52	38	22.66	46	30.03
30			23	12.73	37	22.61	45	30.00
31					36	22.52	44	29.94
32					35	22.41	44	30.90
33					35	23.11	43	30.77
34					34	22.93	42	30.61
35					33	22.73	41	30.43
36					32	22.50	40	30.21
37					31	22.23	40	31.05
38					30	21.94	39	30.77
39					29	21.62	38	30.47
40					28	21.27	37	30.14
41					27	20.89	37	30.90
42					26	20.48	36	30.51
43					25	20.05	35	30.11
44					24	19.59	35	30.81
45					23	19.10	34	30.35
46							33	29.87
47							32	29.37
48							32	29.99
49							31	29.44
50							30	28.87
51							30	29.44
52							29	28.82
53							28	28.18
54							27	27.51
55							27	28.02
56							26	27.31
57							25	26.58
58							25	27.05
59							24	26.27
60							23	25.47

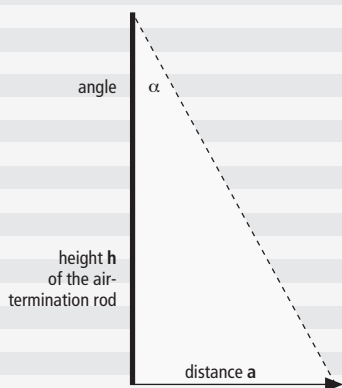


Table 5.1.1.4 Protective angle α depending on the class of lighting protection system

termination system above the reference plane (Figure 5.1.1.12).

Air-termination conductors, air-termination rods, masts and wires should be arranged to ensure that all parts of the building to be protected are situa-



Fig. 5.1.1.17 Protection of small-sized installations on roofs against direct lightning strikes by means of air-termination rods



Fig. 5.1.1.18 Gable roof with conductor holder

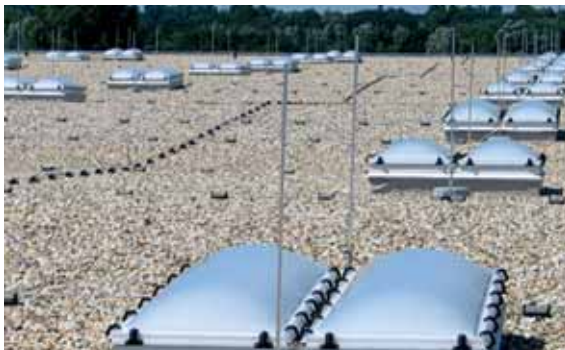


Fig. 5.1.1.19 Flat roof with conductor holders: Protection of the domelights

ted within the volume of protection of the air-termination system.

The protection zone can be “cone-shaped” or “tent-shaped”, if a cable, for example, is spanned over it (Figures 5.1.1.13 to 5.1.1.15).

If air-termination rods are installed on the surface of the roof to protect structures mounted thereon, the protective angle α can be different. In Figure 5.1.1.16, the roof surface is the reference plane for protective angle α_1 . The ground is the reference plane for the protective angle α_2 . Therefore the angle α_2 according to Figure 5.1.1.12 and Table 5.1.1.4 is less than α_1 .

Table 5.1.1.4 provides the corresponding protective angle for each class of lightning protection system and the corresponding distance (zone of protection).

Protective angle method for isolated air-termination systems on roof-mounted structures

Special problems may occur when roof-mounted structures, which are often installed at a later date, protrude from zones of protection, e.g. the mesh. If, in addition, these roof-mounted structures contain electrical or electronic equipment, such as roof-mounted fans, antennas, measuring systems or TV cameras, additional protective measures are required.

If such equipment is connected directly to the external lightning protection system, then, in the event of a lightning strike, partial currents are conducted into the structure. This could result in the destruction of surge sensitive equipment. Direct lightning strikes to such structures protruding above the roof can be prevented by having isolated air-termination systems.

Air-termination rods as shown in Figure 5.1.1.17 are suitable for protecting smaller roof-mounted structures (with electrical equipment).

They form a “cone-shaped” zone of protection and thus prevent a direct lightning strike to the structure mounted on the roof.

The separation distance s must be taken into account when dimensioning the height of the air-termination rod (see Chapter 5.6).

Isolated and non-isolated air-termination systems

When designing the external lightning protection system of a structure, we distinguish between two types of air-termination system:

- ⇒ isolated
- ⇒ non-isolated

The two types can be combined.

The air-termination systems of a **non-isolated** external lightning protection system of a structure can be installed in the following ways:

If the roof is made of non-flammable material, the conductors of the air-termination system can be installed on the surface of the structure (e.g. gable or flat roof). Normally non-flammable building materials are used. The components of the external lightning protection system can therefore be mounted directly on the structure (**Figures 5.1.1.18 and 5.1.1.19**).

If the roof is made of easily inflammable material e.g. thatched roofs, then the distance between the flammable parts of the roof and the air-termination rods, air-termination conductors or air-termination meshes of the air-termination system must not be less than 0.4 m.

Easily inflammable parts of the structure to be protected must not be in direct contact with parts of the external lightning protection system. Neither may they be located under the roofing, which can be punctured in the event of a lightning strike (see also Chapter 5.1.5 Thatched roofs).

With **isolated** air-termination systems, the complete structure is protected against a direct lightning strike via air-termination rods, air-termination masts or masts with cables spanned over them. When installing the air-termination systems, the separation distance s to the structure must be kept (**Figures 5.1.1.20 and 5.1.1.21**).

The separation distance s between the air-termination system and the structure must be kept.

Air-termination systems isolated from the structure are frequently used, when the roof is covered with inflammable material, e.g. thatch or also for ex-installations, e.g. tank installations.

See also Chapter 5.1.5 "Air-termination system for structures with thatched roofs".

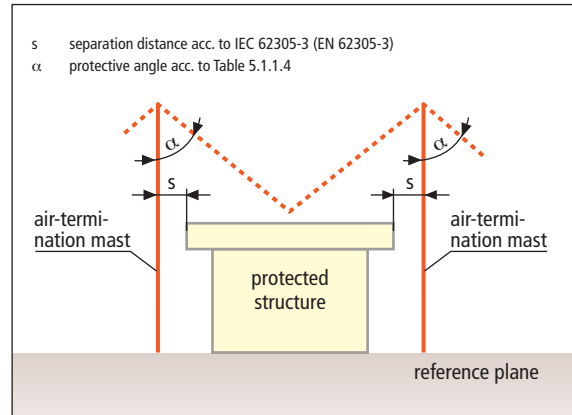


Fig. 5.1.1.20 Isolated external lightning protection system with two separate air-termination masts according to the protective angle method: Projection on a vertical area

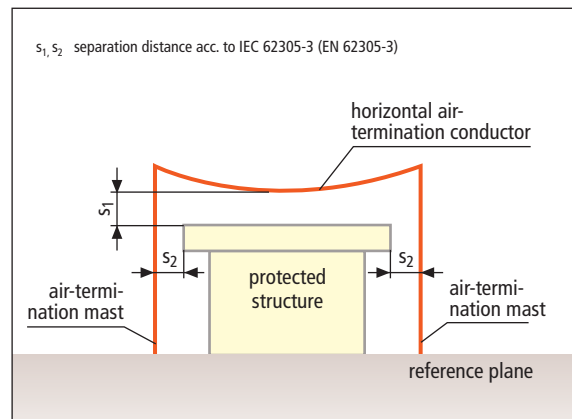


Fig. 5.1.1.21 Isolated external lightning protection system, consisting of two separate air-termination masts, connected by a horizontal air-termination conductor: Projection on a vertical surface via the two masts (vertical section)

A further method of designing isolated air-termination systems consists in securing the air-termination systems (air-termination rods, conductors or cables) with electrically insulating materials such as GRP (glass fibre-reinforced plastic).

This form of isolation can be limited to local use or applied to whole parts of the installation. It is often used for roof-mounted structures such as fan systems or heat exchangers with an electrically conductive connection into the structure (see also Chapter 5.1.8).

Class of LPS	Material	Thick- ness ^a t mm	Thick- ness ^b t [`] mm
I to IV	Lead	-	2.0
	Steel (stainless, galvanised)	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	-	0.7
^a t prevents from puncturing, overheating, and inflaming ^b t [`] only for metal plates, if the prevention of puncturing, overheating, and inflaming is not important			

Table 5.1.1.5 Min. thickness of metal plates

Natural components of air-termination systems

Metal structural parts such as attics, guttering, railings or cladding can be used as natural components of an air-termination system.

If a structure has a steel skeleton construction with a metal roof and facade made of conductive material, these can be used for the external lightning protection system, under certain circumstances.

Sheet metal cladding on the walls or roof of the structure to be protected can be used if the electrical connection between the different parts is permanent. These permanent electrical connections can be made by e.g. brazing, welding, pressing, screwing or riveting, for example.

If there is no electrical connection, a supplementary connection must be made for these elements e.g. with bridging braids or bridging cables.

If the thickness of the sheet metal is not less than the value t' in **Table 5.1.1.5**, and if there is no requirement to take account of a through-melting of the sheets at the point of strike or the ignition of flammable material under the cladding, then such sheets can be used as an air-termination system.

The material thicknesses are not distinguished according to the class of lightning protection system.

If it is, however, necessary to take precautionary measures against through-melting or intolerable heating-up at the point of strike, if the thickness of the sheet metal shall not be less than value t in **Table 5.1.1.5**.

The required thicknesses t of the materials can generally not be complied with, for example, for metal roofs.

For pipes or containers, however, it is possible to meet the requirements for these minimum thicknesses (wall thickness). If, though, the temperature rise (heating-up) on the inside of the pipe or tank represents a hazard for the medium contained therein (risk of fire or explosion), then these must not be used as air-termination systems (see also Chapter 5.1.4).

If the requirements on the appropriate minimum thickness are not met, the components, e.g. conduits or containers, must be situated in an area protected from direct lightning strikes.

A thin coat of paint, 1 mm bitumen or 0.5 mm PVC cannot be regarded as insulation in the event of a direct lightning strike. Such coatings break down when subjected to the high energies deposited during a direct lightning strike.

There must be no coatings on the joints of the natural components of the down-conductor systems.

If conductive parts are located on the surface of the roof, they can be used as a natural air-termination system if there is no conductive connection into the structure.

By connecting, e.g. pipes or electrical conductors into the structure, partial lightning currents can enter the structure and affect or even destroy sensitive electrical / electronic equipment.

In order to prevent these partial lightning currents from penetrating, isolated air-termination systems shall be installed for the aforementioned roof-mounted structures.

The isolated air-termination system can be designed using the rolling sphere or protective angle method. An air-termination system with a mesh size according to the class of lightning protection system used can be installed if the whole arrangement is isolated (elevated) from the structure to be protected by at least the required separation distance s.



Fig. 5.1.2.1 Air-termination system on a gable roof

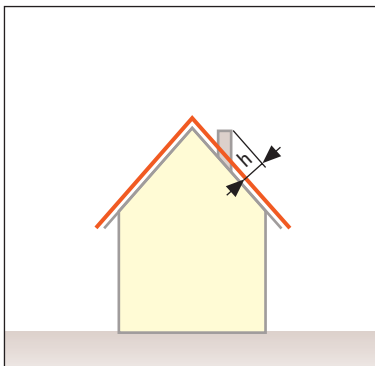


Fig. 5.1.2.2 Height of a roof superstructure made of electrically non-conductive material (e.g. PVC), $h \leq 0.5$ m



Fig. 5.1.2.3 Additional air-termination system for ventilation pipes

A universal system of components for the installation of isolated air-termination systems is described in Chapter 5.1.8.

5.1.2 Air-termination systems for buildings with gable roofs

Air-termination systems on roofs are the metal components in their entirety, e.g. air-termination conductors, air-termination rods, air-termination tips.

The parts of the structure usually hit by lightning strikes, such as the top of the gable, chimneys, ridges and arrises, the edges of gables and eaves, parapets and antennas and other protruding structures mounted on the roof, must be equipped with air-termination systems.

Normally, a reticulated air-termination network is installed on the surface of gabled roofs, said network corresponding to the mesh size of the appropriate class of lightning protection system (e.g. 15 m x 15 m for a lightning protection system Class III) (Figure 5.1.2.1).

By using the ridge and the outer edges of the structure, as well as the metal parts of the structure serving as an air-termination system, the individual meshes can be sited as preferred. The air-termination conductors on the outer edges of the structure must be installed as close to the edges as possible.

Generally, the metal gutter is used for closing the "mesh" of the air-termination system on the roof surface. If the gutter itself is connected so as to be electrically conductive, a gutter clamp is mounted

at the crossover of the air-termination system and the gutter.

Roof-mounted structures made of electrically **non-conductive** material (e.g. PVC vent pipes) are considered to be sufficiently protected if they do not protrude more than $h = 0.5$ m from the plane of the mesh (Figure 5.1.2.2).

If the protrusion is $h > 0.5$ m, the structure must be equipped with an air-termination system (e.g. interception tip) and connected to the nearest air-termination conductor. One way of doing this would be to use a wire with a diameter of 8 mm up to a maximum free length of 0.5 m, as shown in Figure 5.1.2.3.

Metal structures mounted on the roof without conductive connection into the structure do not need to be connected to the air-termination system if all the following conditions are met:

- ⇒ Structures mounted on the roof may protrude a maximum distance of 0.3 m from the plane of the mesh
- ⇒ Structures mounted on the roof may have a maximum enclosed area of 1 m² (e.g. dormer windows)
- ⇒ Structures mounted on the roof may have a maximum length of 2 m (e.g. sheet metal roofing parts)

Only if all three conditions are met, no terminal is required.



Fig. 5.1.2.4 Building with photovoltaic system
Ref.: Wettingfeld Lightning Protection, Krefeld, Germany

Furthermore, with the conditions stated above, the separation distance to the air-termination conductors and down-conductor systems must be maintained (**Figure 5.1.2.4**).

Air-termination rods for chimneys must be erected to ensure that the whole chimney is in the zone of protection. The protective angle method is applied when dimensioning the air-termination rods.

If the stack is brick-built or constructed with pre-formed sections, the air-termination rod can be mounted directly on the stack.

If there is a metal insert pipe in the interior of the stack, e.g. as found when redeveloping old buildings, the separation distance to this conductive component must be kept. This is an example where isolated air-termination systems are used and the air-termination rods are erected with distance holders. The inserted metal pipe must be connected to the equipotential bonding. The assembly to protect parabolic antennas in particular is similar to that to protect stacks with an internal stainless steel pipe.

In the event of a direct lightning strike to antennas, partial lightning currents can enter the structure to be protected via the shields of the coaxial cables and cause the effects and destruction previously described. To prevent this, antennas are equipped with isolated air-termination systems (e.g. air-termination rods) (**Figure 5.1.2.5**).

Air-termination systems on the ridge have a tent-shaped zone of protection (according to the protective angle method). The angle depends on the height above the reference plane (e.g. surface of



Fig. 5.1.2.5 Antenna with air-termination rod

the earth) and the class of lightning protection system chosen.

5.1.3 Air-termination systems for flat-roofed structures

An air-termination system for structures with flat roofs (**Figures 5.1.3.1** and **5.1.3.2**) is designed using the mesh method. A mesh-type air-termination system with a mesh size corresponding to the class of lightning protection system is installed on the roof (**Table 5.1.1.3**).

Figure 5.1.3.3 illustrates the practical application of the meshed air-termination system in combination with air-termination rods to protect the structures mounted on the roof, e.g. domelights, photovoltaic cells or fans. Chapter 5.1.8 shows how to deal with these roof-mounted structures.

Roof conductor holders on flat roofs are laid at intervals of approx. 1 m. The air-termination conductors are connected with the attic, this being a natural component of the air-termination system. As the temperature changes, so does the length of the materials used for the attic, and hence the individual segments must be equipped with "slide plates".

If the attic is used as an air-termination system, these individual segments must be permanently interconnected so as to be electrically conductive without restricting their ability to expand. This can

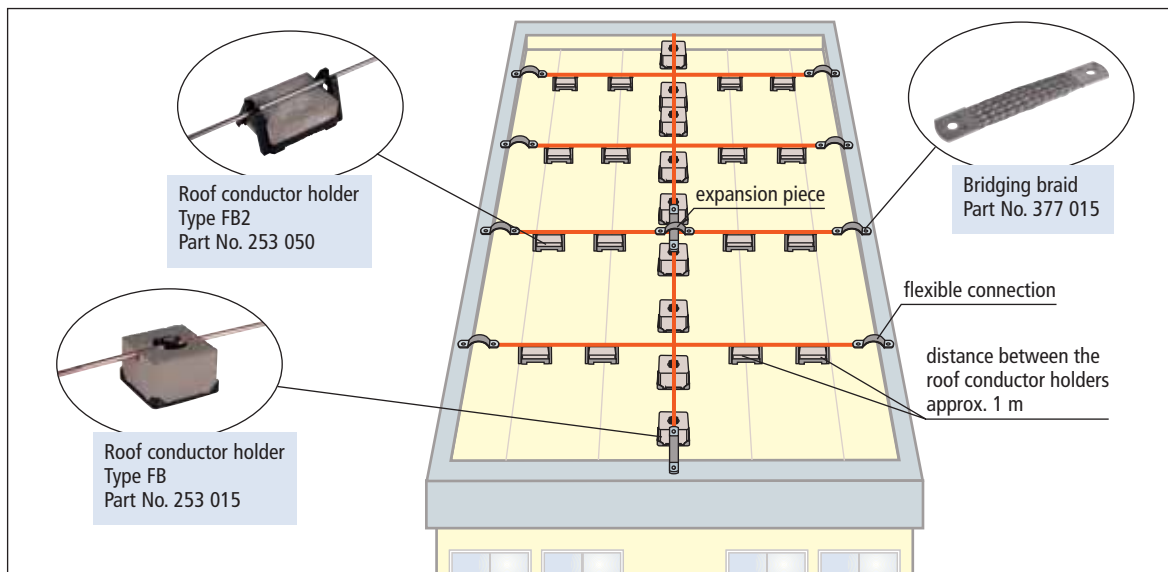


Fig. 5.1.3.1 Air-termination system



Fig. 5.1.3.2 Air-termination system on a flat roof



Fig. 5.1.3.3 Use of air-termination rods



Fig. 5.1.3.4 Bridged attic

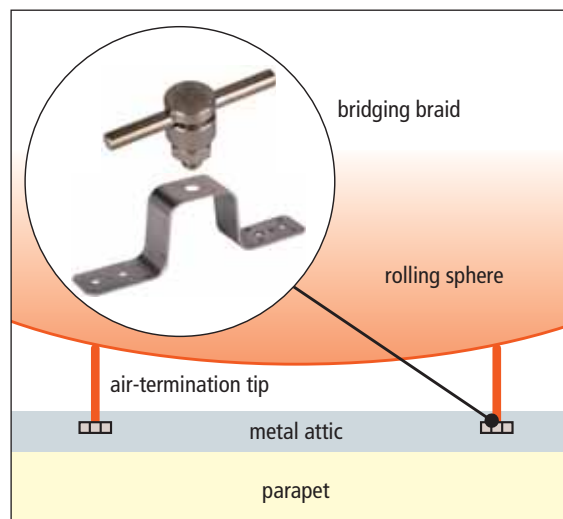


Fig. 5.1.3.5 Example how to protect a metal roof attic, if melting through is unacceptable (front view)

be achieved by means of bridging braids, straps or cables (**Figure 5.1.3.4**).

The changes in length caused by changes in temperature must also be taken into account with air-termination conductors and down-conductor systems (see Chapter 5.4).

A lightning strike to the attic can cause the materials used to melt through. If this is unacceptable, a

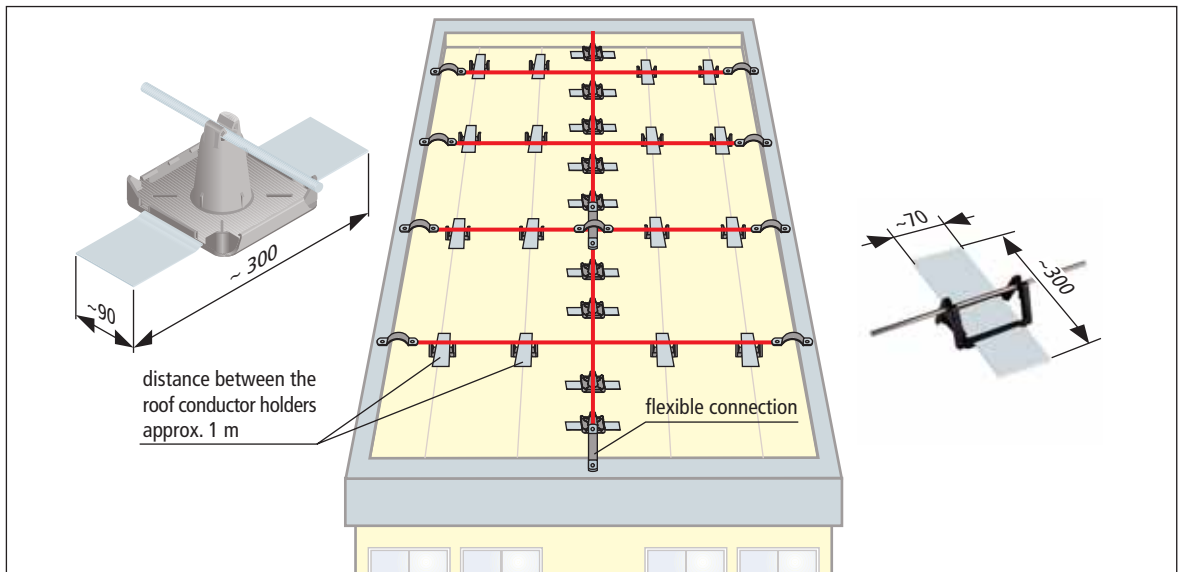


Fig. 5.1.3.6 Synthetic flat roof sheetings – Roof conductor holder Type KF / KF2

supplementary air-termination system, e.g. with air-termination tips, must be installed, its location being determined by using the rolling sphere method (Figure 5.1.3.5).

Conductor holders for flat roofs, homogeneously welded

In the wind, roof sheetings can move across the roof surface horizontally, if they are only fixed mechanically/laid on the surface. A special position fixing is required for the air-termination conductor for preventing the conductor holders for air-termination systems from being displaced on the smooth surface. Conventional roof conductor holders cannot be permanently bonded to roof sheetings since the latter do not usually permit the application of adhesives.

A simple and safe way of fixing the position is to use roof conductor holders Type KF in combination with straps (cut the strips to fit) made of the roof sheeting material. The strap is clamped into the plastic holder and both sides are welded onto the seal. Holder and strap should be positioned immediately next to a roof sheeting joint at a distance of approx. 1 m. The strip of foil is welded to the roof sheeting according to the manufacturer of the roof sheeting. This prevents air-termination conductors on flat roofs from being displaced.

If the slope of the roof is greater than 5 °, each roof conductor holder must be equipped with a position fixing element. If the synthetic roof sheetings are secured by mechanical means, the roof conductor holders must be arranged in the immediate vicinity of the mechanical fixing elements.

When carrying out this work, it must be considered that welding and bonding work on the seal affect the guarantee provided by the roofer.

The work to be carried out must therefore only be done with the agreement of the roofer responsible for the particular roof, or be carried out by him himself (Figure 5.1.3.6).

5.1.4 Air-termination systems on metal roofs

Modern industrial and commercial purpose-built structures often have metal roofs and facades. The metal sheets and plates on the roofs are usually 0.7 – 1.2 mm thick.

Figure 5.1.4.1 shows an example of the construction of a metal roof.

When the roof is hit by a direct lightning strike, melting through or vaporisation can cause a hole formed at the point of strike. The size of the hole depends on the energy of the lightning strike and



Fig. 5.1.4.1 Types of metal roofs, e.g. roofs with round standing seam



Fig. 5.1.4.2 Example of damage: Metal plate cover

the characteristics of the material, (e.g. thickness). The biggest problem here is the subsequent damage, e.g. water entering at this point. Days or weeks can pass before this damage is noticed. The

Suitable for all classes of lightning protection system	
Distance of the horizontal conductors	Height of the air-termination tip*)
3 m	0.15 m
4 m	0.25 m
5 m	0.35 m
6 m	0.45 m
*) recommended values	

Table 5.1.4.1 Lightning protection for metal roofs – Height of the air-termination tips

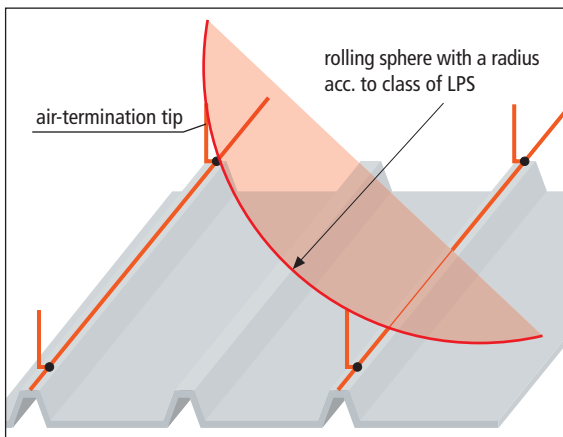


Fig. 5.1.4.3 Air-termination system on a metal roof – Protection against holing

roof insulation becomes damp and / or the ceiling becomes wet and is no longer rainproof.

One example of damage, assessed using BLIDS (Blitz-Informationen Dienst von Siemens – Siemens Lightning Information Service) illustrates this problem (Figure 5.1.4.2). A current of approx. 20,000 A struck the sheet metal and made a hole (Figure 5.1.4.2: Detail A). Since the sheet metal was not earthed by a down-conductor system, flash-overs to natural metal components in the wall occurred in the area around the fascia (Figure 5.1.4.2: Detail B), which also caused a hole.

To prevent such kind of damage, a suitable external lightning protection system with wires and clamps capable of carrying lightning currents must be installed even on a “thin” metal roof. The IEC 62305-3 (EN 62305-3) lightning protection standard clearly illustrates the risk of damage to metal roofs. Where an external lightning protection system is required, the metal sheets must have the minimum values stated in Table 5.1.1.5.

The thicknesses t are not relevant for roofing materials. Metal sheets with a thickness t' may only be used as a natural air-termination system if puncturing, overheating and melting is tolerated. The owner of the structure must agree to tolerate this type of roof damage, since there is no longer any guarantee that the roof will offer protection from the rain. Also the Rules of the German Roofing Trade concerning lightning protection on and attached to roofs require the agreement of the owner.

If the owner is not prepared to tolerate damage to the roof in the event of a lightning strike, then a separate air-termination system must be installed

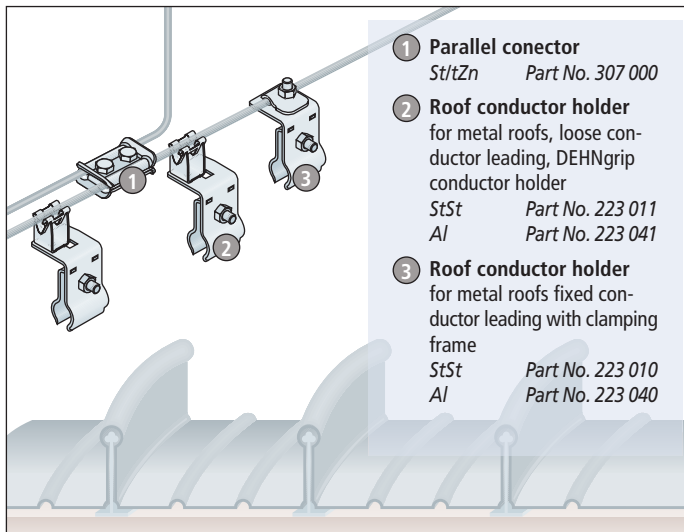


Fig. 5.1.4.4a Conductor holders for metal roofs – Round standing seam

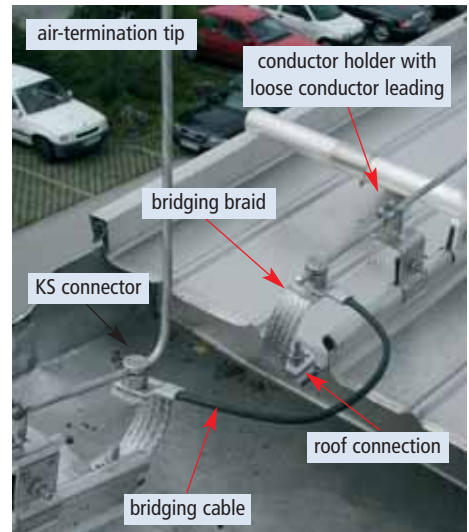


Fig. 5.1.4.4b Conductor holder for metal roofs – Round standing seam

on a metal roof. The air-termination system must be installed to ensure that the rolling sphere (radius r which corresponds to the class of lightning protection system chosen) does not touch the metal roof (**Figure 5.1.4.3**).

When mounting the air-termination system it is recommended to install a so-called “hedgehog roof” with longitudinal conductors and air-termination tips.

In practice, the heights of air-termination tips according to **Table 5.1.4.1** are tried and tested, regardless of the class of lightning protection system involved.

Holes must not be drilled into the metal roof when fixing the conductors and air-termination tips. Various conductor holders are available for the different types of metal roofs (round standing seam, standing seam, trapezoidal). **Figure 5.1.4.4a** shows one possible design for a metal roof with round standing seam.

When installing the conductors, care must be taken that the conductor holder located at the highest point of the roof must be designed with a fixed conductor leading, whereas all other conductor holders must be designed with a loose conductor leading because of the linear compensation



Fig. 5.1.4.5 Model construction of a trapezoidal sheet roof, conductor holder with clamping frame



Fig. 5.1.4.6 Model construction of a roof with standing seam



Fig. 5.1.4.7 Air-termination rod for a dome-light on a roof with round standing seam

caused by changes in temperature (Figure 5.1.4.4b).

The conductor holder with fixed conductor leading is illustrated in Figure 5.1.4.5 using the example of a trapezoidal sheet roof.

Figure 5.1.4.5 also shows an air-termination tip next to the conductor holder. The conductor holder must be hooked into the fixing screw above the covering plate for the drill hole to prevent any entering of water.

Figure 5.1.4.6 uses the example of a round standing seam roof to illustrate the loose conductor leading.

Figure 5.1.4.6 also shows the connection to the roof with round standing seam at the roof edge, which is capable of carrying currents.

Unprotected installations projecting above the roof, e.g. domelights and chimney covers, are exposed points of strike for a lightning discharge. In order to prevent these installations from being struck by a direct lightning strike, air-termination rods must be installed adjacent to the installations projecting above the roof. The height of the air-termination rod results from the protective angle α (Figure 5.1.4.7).

5.1.5 Principle of an air-termination system for structures with thatched roof

The design of lightning protection systems Class III generally meets the requirements of such a structure. In particular individual cases, a risk analysis based on IEC 62305-2 (EN 62305-2) can be carried out.

The air-termination conductors on such roofs (made of thatch, straw or rushes) must be fastened across isolating supports to be free to move. Certain distances must also be maintained around the eaves.

In case of subsequent installation of a lightning protection system on a roof, the distances must be increased. This allows to maintain the necessary minimum distances when re-roofing is carried out. For a lightning protection system Class III, the typical distance of the down-conductor system is 15 m.

The exact distance of the down-conductor systems from each other results from calculating the separation distance s in accordance with IEC 62305-3 (EN 62305-3).

Chapter 5.6 explains how to calculate the separation distance.

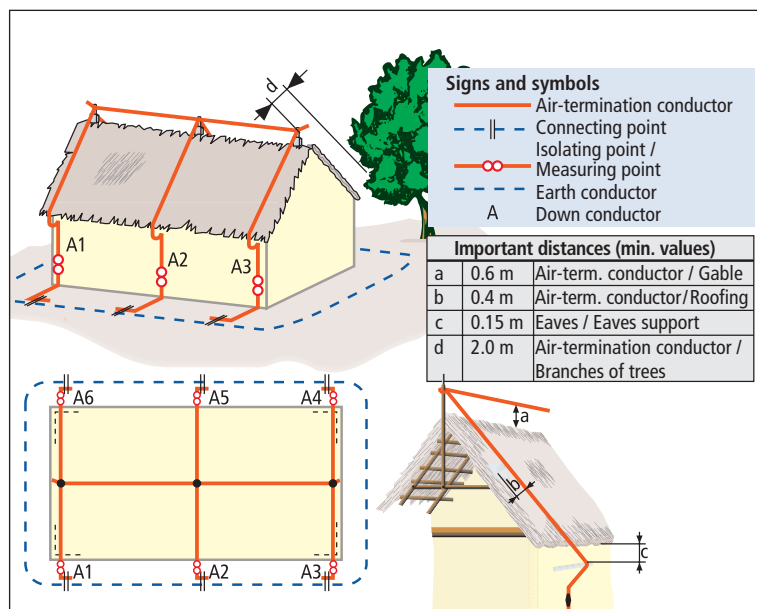


Fig. 5.1.5.1 Air-termination system for buildings with thatched roofs

Ideally, ridge conductors should have spans up to around 15 m, and down-conductor systems up to around 10 m without additional supports.

Fastening posts must be tightly connected to the roof structure (rafters and rails) by means of bolts and washers (Figures 5.1.5.1 to 5.1.5.3).

Metal components situated above the roof surface (such as weather vanes, irrigation systems, antennas, metal plates, conductors) must be entirely in the protected volume of isolated air-termination systems.

In such cases, effective protection against lightning can only be achieved with an isolated external lightning protection system with

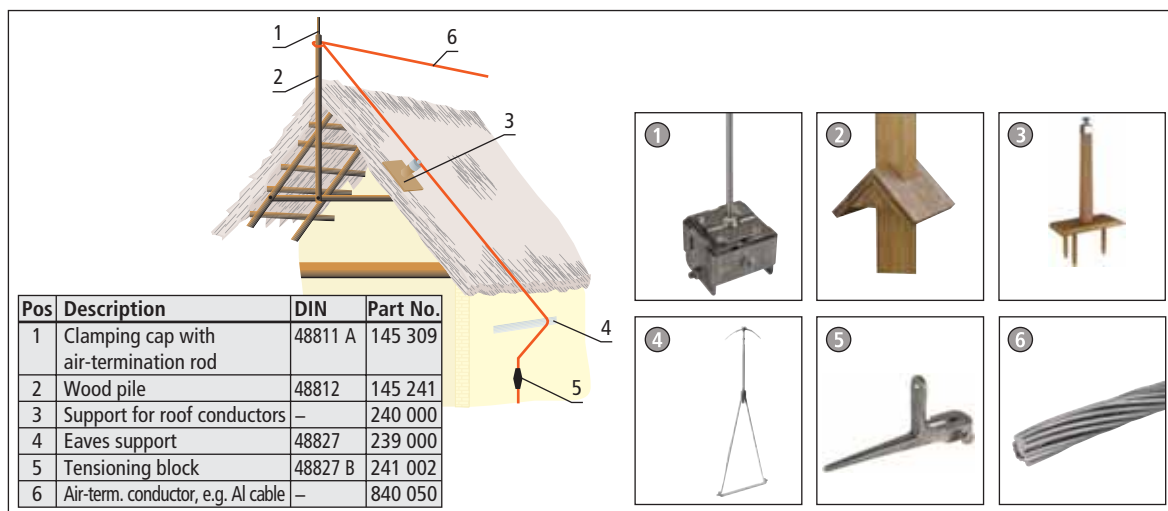


Fig. 5.1.5.2 Components for thatched roofs

air-termination rods near the structure, or air-termination conductors or interconnected air-termination masts adjacent to the structure.

If a thatched roof borders onto metal roofing material, and if the structure has to be equipped with an external lightning protection system, then an electrically non-conductive roofing material at least 1 m wide, e.g. in plastic, must be inserted between the thatched roof and the other roof.

Tree branches must be kept at least 2 m away from a thatched roof. If trees are very close to, and higher than, a structure, then an air-termination conductor must be mounted on the edge of the roof facing the trees (edge of the eaves, gable) and connected to the lightning protection system. The necessary distances must be maintained.

A further way of protecting structures with thatched roofs against a strike of lightning is to erect air-termination masts so that the whole structure is in the protected volume.



Fig. 5.1.5.3 Thatched roof

This method can be found in Chapter 5.1.8 isolated air-termination system (steel telescopic lightning protection masts).

A new and architecturally very attractive possibility of isolated lightning protection is the use of isolated down conductor systems.

Example for the installation of isolated down conductor systems: Redevelopment of the roof of a historical farmhouse in Lower Saxony (Figure 5.1.5.4).

Referring to the building regulations (LBO) of the respective federal state as well as to the model building regulations (MBO), the competent building authority decides about the necessity of a lightning protection system.



Fig. 5.1.5.4 Historical farmhouse with external lightning protection (Ref. Photo: Hans Thormählen GmbH & Co.KG)

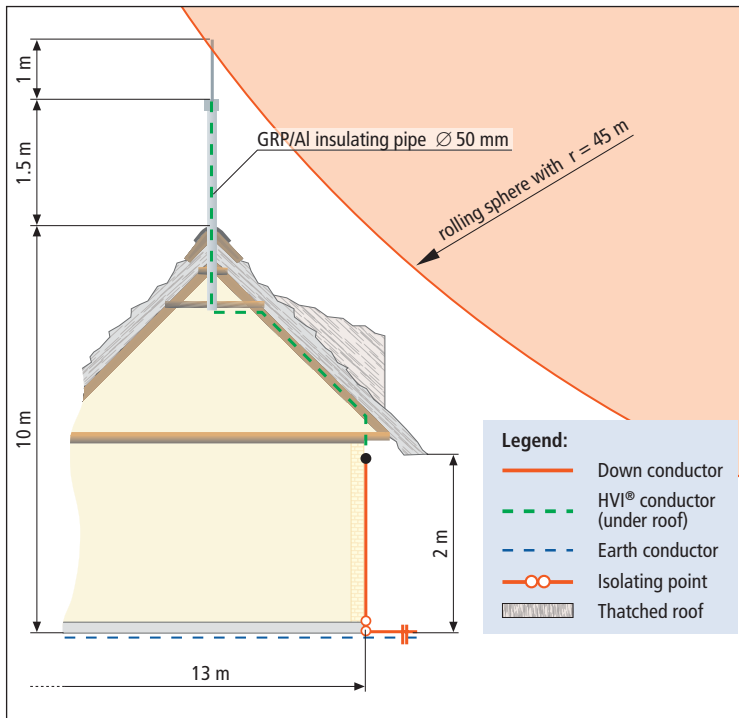


Fig. 5.1.5.5 Sectioning at the central building

The building regulations of Lower Saxony (NBauO) for example stipulate in § 20 (3) that:

“Buildings or structures which due to the location, type of construction or use are particularly susceptible to lightning strikes, or where such a strike can have serious consequences, must be equipped with permanently effective lightning protection systems.”

With regard to the increasing damage events caused by lightning strikes and surges, property insurers require that measures of lightning and surge protection are taken prior to the conclusion of new, or adjustment of existing insurance contracts. Basis for the risk assessment is a risk analysis according to IEC 62305-2 (EN 62305-2).

At the historical farmhouse a lightning protection system Class III has been installed, which meets the standard requirements for buildings with thatched roofs IEC 62305-3 (EN 62305-3).

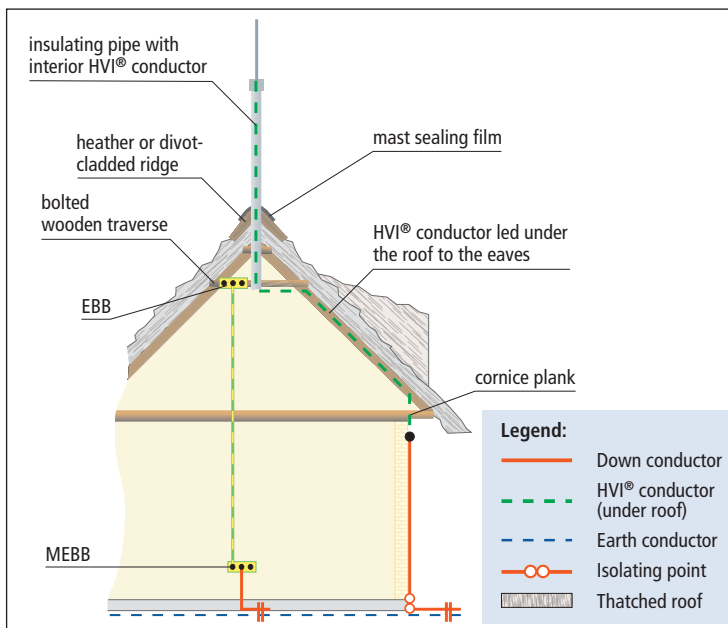


Fig. 5.1.5.6 Schematic diagram and diagram of the down conductor installation at the rafter





Fig. 5.1.5.7 HVI conductor led through the cornice plank

The heather-cladded ridge of the object is protected by a reticulated plastic cover to avoid abrasion by birds.

Before designing of the air-termination system, the protected volumes are to be determined by the rolling sphere method. A rolling sphere radius of 45 m is applicable in case of a lightning protection system Class III according to the standard specifications. The height of the air-termination system was ascertained to be 2.30 m, thus the two stacks at the ridge and the three new dormers at the one side of the roof are within the protected volume (Figure 5.1.5.5).

An insulating pipe (Glass Fibre Reinforced Unsaturated Plastic) was chosen to keep the air-termination system correspondingly elevated and to support the isolated down-conductor system. The lower part of the insulating pipe is aluminium to ensure the mechanical stability. Due to the induction of neighbouring components unwanted sparking is possible in this section. To avoid this, there are no earthed parts or electrical equipment within a distance of 1 m from the air-termination system.

The electrical isolation of air-termination systems and down-conductor systems on the one hand and of the metal installations to be protected and the systems of power supply and information technology of the building or structure to be protected on the other hand, can be achieved by the separation distance s between these conductive parts. This must be determined according to IEC 62305-3

(EN 62305-3). The isolated HVI conductor is specified with an equivalent separation distance in air of $s = 0.75$ m or $s = 1.50$ m for solid building materials. Figure 5.1.5.6 shows how the down conductor system is arranged.

The HVI conductor is run in an insulating pipe. The construction requires a down leading of the HVI conductor via a central earthing busbar, the equipotential bonding measures being performed by a flexible conductor H07V-K 1 x 16 mm². The insulating pipe is fixed at a special construction (wooden traverse) and further down, the down conductors are routed along the rafters of the roof construction underneath the battens (Figure 5.1.5.6).

At the eaves, the HVI conductors are led through the cornice plank (Figure 5.1.5.7).

For architectural reasons aluminium down conductors are installed further down. Like for the whole installation, the crossover of the HVI conductor to the uninsulated, bare down conductor near the earthing system is effected on the basis of the mounting instructions of the DEHNconductor system. A sealing unit was not necessary.

5.1.6 Walkable and trafficable roofs

It is not possible to mount air-termination conductors (e.g. with concrete blocks) on trafficable roofs. One possible solution is to install the air-termination conductors in either concrete or in the joints between the sections of the roadway. If the air-termination conductor is installed in these joints, mushroom head collectors are installed at the intersections of the mesh as defined points of strike.

The mesh size must not exceed the value according to the class of lightning protection system (see Chapter 5.1.1, Table 5.1.1.3).

If it can be guaranteed that no persons will be on this area during a thunderstorm, then it is sufficient to install the measures described above.

Persons who can go onto this storey of the car park must be informed by means of a sign that they must immediately clear this storey when a thunderstorm occurs, and not return for the duration of the storm (Figure 5.1.6.1).

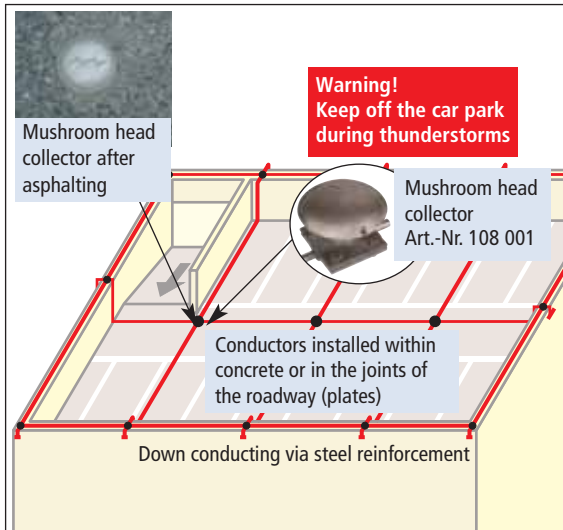


Fig. 5.1.6.1 Lightning protection for car park roofs – Building protection

If it is also possible that persons are on the roof during a thunderstorm, then the air-termination system must be designed to protect these persons, assuming they have a height of 2.5 m (with outstretched arm) from direct lightning strikes.

The air-termination system can be dimensioned using the rolling sphere or the protective angle method according to the class of lightning protection system (Figure 5.1.6.2).

These air-termination systems can also be constructed from spanned cables or air-termination rods. These air-termination rods are secured to structural elements such as parapets or the like, for example.

Furthermore, lightning masts, for example, can also act as air-termination rods to prevent life hazard. With this version, however, attention must be paid to the partial lightning currents which can be conducted into the structure via the power lines. It is imperative to have lightning equipotential bonding measures for these lines.

5.1.7 Air-termination system for green and flat roofs

A planted roof can make economic and ecological sense. This is because it provides noise insulation,

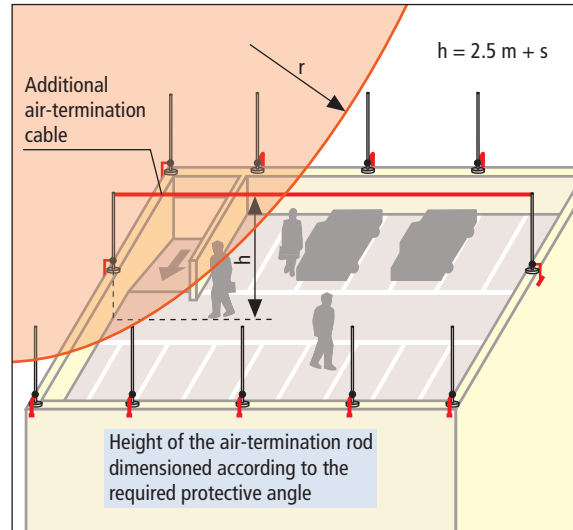


Fig. 5.1.6.2 Lightning protection for car park roofs – Building and life protection IEC 62305-3 (EN 62305-3); Annex E

protects the roof skin, suppresses dust from the ambient air, provides additional heat insulation, filters and retains rainwater and is a natural way of improving the living and working conditions. Moreover, in many regions it is possible to obtain grants from public funds for cultivating plants on the roof. A distinction is made between so-called extensive and intensive cultivation. An extensive planted area requires little care, in contrast to an intensive planted area which requires fertiliser, irrigation and cutting. For both types of planted area, either earth substrate or granulate must be laid on the roof.

It is even more expensive if the granulate or substrate has to be removed because of a direct lightning strike.

If there is no external lightning protection system, the roof seal can be damaged at the point of strike.

Experience has shown that, regardless of the type of care required, the air-termination system of an external lightning protection system can, and should, also be installed on the surface of a green roof.

For a meshed air-termination system, the IEC 62305-3 (EN 62305-3) lightning protection stan-



Fig. 5.1.7.1 Green roof



Fig. 5.1.7.2 Air-termination system on a green roof



Fig. 5.1.7.3 Conductor leading on the covering layer

standard prescribes a mesh size which depends on the class of lightning protection system chosen (see Chapter 5.1.1, Table 5.1.1.3). An air-termination conductor installed inside the covering layer is difficult to inspect after a number of years because the air-termination tips or mushroom head collectors are overgrown and no longer recognisable, and frequently damaged by maintenance work. Moreover, air-termination conductors installed inside the covering layer are more susceptible to corrosion. Conductors of air-termination meshes installed uniformly on top of the covering layer are easier to inspect even if they become overgrown, and the height of the interception system can be lifted up by means of air-termination tips and rods and “grown” with the plants on the roof. Air-termination systems can be designed in different ways. The usual way is to install a meshed air-termination net with a mesh size of 5 m x 5 m (lightning protection system Class I) up to a max. mesh size of 15 m x 15 m (lightning protection system Class III) on the roof surface, regardless of

the height of the structure. It is preferable to determine the installation site of the mesh considering the external edges of the roof and any metal structures acting as an air-termination system.

Stainless steel (Material No. 1.4571) has proven to be a good material for the conductors of air-termination systems on planted roofs. Aluminium wire must not be used for installing conductors in the covering layer (in the earth substrate or granulate), (Figures 5.1.7.1 to 5.1.7.3).

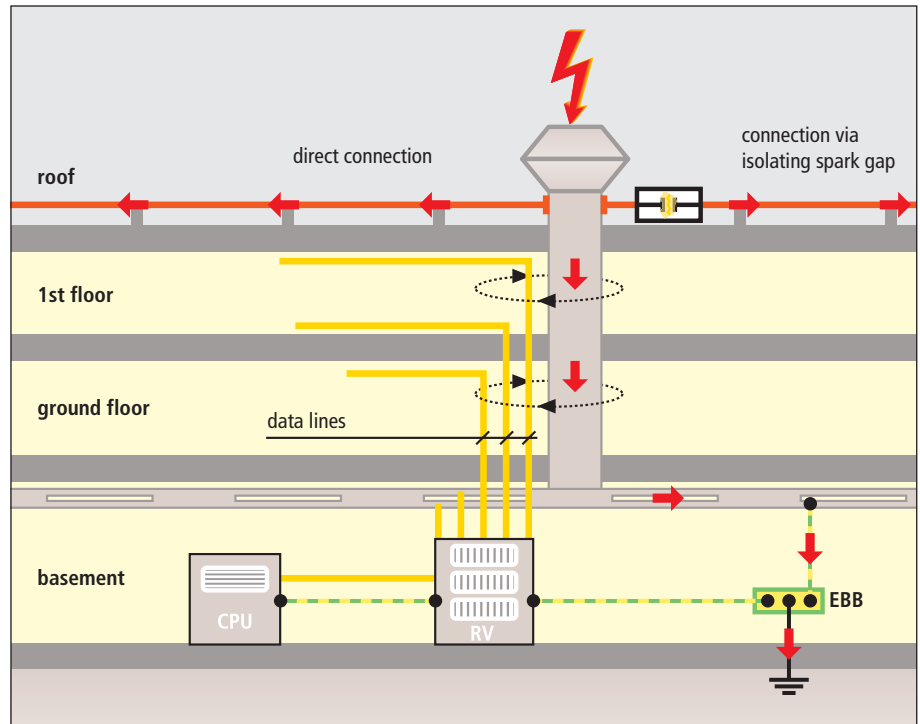


Fig. 5.1.8.1 Connection of roof-mounted structures



Fig. 5.1.8.2 Isolated air-termination system, protection provided by an air-termination rod

5.1.8 Isolated air-termination systems

Roof-mounted structures such as air conditioning and cooling systems, e.g. for mainframes, are nowadays used on the roofs of larger office blocks and industrial structures. Antennas, electrically controlled domelights, advertising signs with integrated lightning and all other protruding roof-mounted structures having a conductive connection, e.g. via electrical cables or ducts, into the structure, must be treated in a similar way.

According to the state of the art for lightning protection, such roof-mounted structures are protected against direct lightning strikes by means of separately mounted air-termination systems. This prevents partial lightning currents from entering the structure, where they would affect or even destroy the sensitive electrical/electronic installations.

In the past, these roof-mounted structures were connected directly.

This direct connection meant that parts of the lightning current were conducted into the structure. Later, "indirect connection" via a spark gap was introduced. This meant that direct lightning strikes to the roof-mounted structure could also flow away via the "internal conductors" to some extent, and in the event of a more distant lightning strike to the structure, the spark gap should not operate. The operating voltage of approx. 4 kV was almost always attained and hence partial



Fig. 5.1.8.3 Air-termination rod with distance holder

lightning current was also carried into the structure via the electrical cable, for example. This can affect or even destroy electrical or electronic installations inside the structure.

The only way of preventing these currents to be carried in is to use isolated air-termination systems which maintain the separation distances.

Figure 5.1.8.1 shows a partial lightning current penetrating the inside of the structure.

These widely different roof-mounted structures can be protected by various designs of isolated air-termination systems.

Air-termination rods

For smaller roof-mounted structures (e.g. small fans) the protection can be achieved by using individual, or a combination of several, air-termination rods. Air-termination rods up to a height of 2.0 m can be fixed with one or two concrete bases piled on top of each other (e.g. Part No. 102 010) as self supporting installation (**Figure 5.1.8.2**).

If air-termination rods are higher than 2.5 m or 3.0 m, they must be fixed at the object to be protected by distance holders made of electrically insulating material (e.g. DEHNiso distance holder) (**Figure 5.1.8.3**).

Angled supports are a practical solution when air-termination rods also have to be secured against



Fig. 5.1.8.4 Angled support for air-termination rods



Fig. 5.1.8.5 Supporting element for the air-termination rod



Fig. 5.1.8.6 Isolated air-termination system for photovoltaic system

the effects of side winds (**Figures 5.1.8.4 and 5.1.8.5**).

If higher air-termination rods are required, e.g. for larger roof-mounted structures, which nothing can be secured to, the air-termination rods can be installed by using special supports.

Self-supporting air-termination rods up to a height of 8.5 m can be installed by using a tripod. These supports are fixed to the floor with standard concrete bases (one on top of another). Additional guy lines are required above a free height of 6 m in order to withstand the stresses caused by the wind.

These self-supporting air-termination rods can be used for a wide variety of applications (e.g. antennas, PV installations). The special feature of this type of air-termination system is its short installation time as no holes need to be drilled and only few elements need to be screwed together (**Figures 5.1.8.6 to 5.1.8.7**).

For protecting complete structures or installations (e.g. PV installations, ammunition depots) with air-termination rods, lightning protection masts are used. These masts are installed in a concrete founda-

tion. Free heights of 19 m above ground level can be achieved, even higher, if custom-made ones are used. It is also possible to span a cable between these masts if they are especially designed for this purpose. The standard lengths of the steel telescopic lightning protection masts are supplied in sections, offering enormous advantages for transportation.

Further information (e.g. installation, assembly) about these steel telescopic lightning protection masts can be found in Installation Instructions No. 1574 (**Figures 5.1.8.8 and 5.1.8.9**).

Spanned over by cables or conductors

According to IEC 62305-3 (EN 62305-3), air-termination conductors can be installed above the structure to be protected.

The air-termination conductors generate a tent-shaped protective space at the sides, and a cone-shaped one at the ends. The protective angle α depends on the class of lightning protection system and the height of the air-termination system above the reference plane.



Fig. 5.1.8.7 Isolated air-termination system for roof-mounted structures



Fig. 5.1.8.8 Additional protection in the transition area by anticorrosive band for underground application



Fig. 5.1.8.9 Installation of a steel telescopic lightning protection mast



Fig. 5.1.8.10 Installed air-termination system
Ref.: Blitzschutz Wettingfeld, Krefeld, Germany

The rolling sphere method with its corresponding radius (according to the class of lightning protection system) can also be used to dimension the conductors or cables.

The mesh type of air-termination system can also be used if an appropriate separation distance s between the components of the installation and the air-termination system must be maintained. In such cases, isolating distance holders in concrete bases are installed vertically, for example, for guiding the mesh on an elevated level (**Figure 5.1.8.10**).

DEHNiso-Combi

A user-friendly way of installing conductors or cables in accordance with the three different design methods for air-termination systems (rolling sphere, protective angle, mesh) is provided by the DEHNiso-Combi programme of products.

The aluminium insulating pipes with “isolating distance” (GRP – Glass-fibre Reinforced Plastic) which are fixed to the object to be protected, provide a way of guiding the cables. By means of the GRP distance holder, a subsequently separate guiding to the down-conductor system or supplementary air-termination systems (e.g. mesh) is realised.

Further information about the application is contained in the brochures DS 123E, DS 111E and in the set of installation instructions No. 1475.



Fig. 5.1.8.11 Tripod support for self-supporting insulating pipes



Fig. 5.1.8.12 Isolated air-termination systems with DEHNiso-Combi

The types of design described can be combined with each other as desired to adapt the isolated air-termination systems to the local conditions (**Figures 5.1.8.11 to 5.1.8.14**).



Fig. 5.1.8.13 Detail picture of DEHNiso-Combi



Fig. 5.1.8.14 Isolated air-termination system with DEHNiso-Combi

5.1.9 Air-termination system for steeples and churches

External lightning protection system

According to the German standard DIN EN 62305-3, Supplement 2, lightning protection systems Class III meet the normal requirements for churches and steeples. In particular individual cases, for example

in the case of culturally significant structures, a special risk analysis in accordance with IEC 62305-2 (EN 62305-2) must be carried out.

Nave

According to the German standard DIN EN 62305-3, Supplement 2, the nave must have its own lightning protection system and, if a steeple is attached, this system must be connected by the shortest route with a down-conductor system of the steeple. In the transept, the air-termination conductor along the transverse ridge must be equipped with a down-conductor system at each end.

Steeple

Steeple up to a height of 20 m must be equipped with a down-conductor system. If steeple and nave are joined, then this down-conductor system must be connected to the external lightning protection system of the nave by the shortest route (**Figure 5.1.9.1**). If the down-conductor system of the steeple coincides with a down-conductor system of the nave, then a common down-conductor system can be used at this location. According to the German standard DIN EN 62305-3, Supplement 2, steeples above 20 m in height must be provided



Fig. 5.1.9.1 Installing the down-conductor system at a steeple

with at least two down conductors. At least one of these down conductors must be connected with the external lightning protection system of the nave via the shortest route.

Down-conductor systems on steeples must always be guided to the ground on the outside of the steeple. The installation inside the steeple is not allowed (DIN EN 62305-3 Supplement 2). Further, the separation distances to metal components and electrical installations in the steeple (e.g. clock mechanisms, belfry) and under the roof (e.g. air conditioning, ventilation and heating systems) must be maintained by suitable arrangement of the external lightning protection system. The required separation distance can become a problem especially at the clock. In this case, the conductive connection into the structure can be replaced with an isolating connector (e.g. a GRP pipe) to prevent hazardous sparking in parts of the external lightning protection system.

In more modern churches built with reinforced concrete, the reinforcement steels can be used as down-conductor systems if it can be ensured that they provide a continuous conductive connection. If pre-cast reinforced concrete parts are used, the reinforcement may be used as a down-conductor system if terminals to connect the reinforcement continuously are provided on the pre-cast concrete parts.

In Germany the lightning equipotential bonding with the electronic equipment (power system, telephone and public address system) shall be effected at the entrance to the building and for the bells control and timing system in the steeple and at the control and timing system, in accordance with Supplement 2 of DIN EN 62305-3.

5.1.10 Air-termination systems for wind turbines (WT)

Requirement for protection against lightning

IEC 61400-24 describes measures required to protect wind turbines against lightning. In the certification directives of the German Lloyd, a lightning protection system Class III is required for WT hubs in a height of 60 m and Class II if the hub is in a height of more than 60 m. In case of offshore plants a lightning protection system Class I is

required. This can control lightning strikes with currents measuring up to 200,000 A. This requirements are based on the experience made at the operation of WT and on the assessment of the risk of damage according to IEC 62305-2 (EN 62305-2).

Principle of an external lightning protection system for wind turbines

The external lightning protection system comprises air-termination systems, down-conductor systems and an earth termination system and protects against mechanical destruction and fire. Lightning strikes to wind turbines usually affect the rotor blades. Hence, receptors, for example, are integrated to determine defined points of strike (Figure 5.1.10.1).

In order to allow the coupled lightning currents to flow to earth in a controlled way, the receptors in the rotor blades are connected to the hub with a metal interconnecting conductor (solid tape conductor St/tZn 30 mm x 3.5 mm or copper cable 50 mm²). Carbon fibre brushes or air spark gaps then, in turn, bridge the ball-bearings in the head of the nacelle in order to avoid the welding of the revolving parts of the structure.

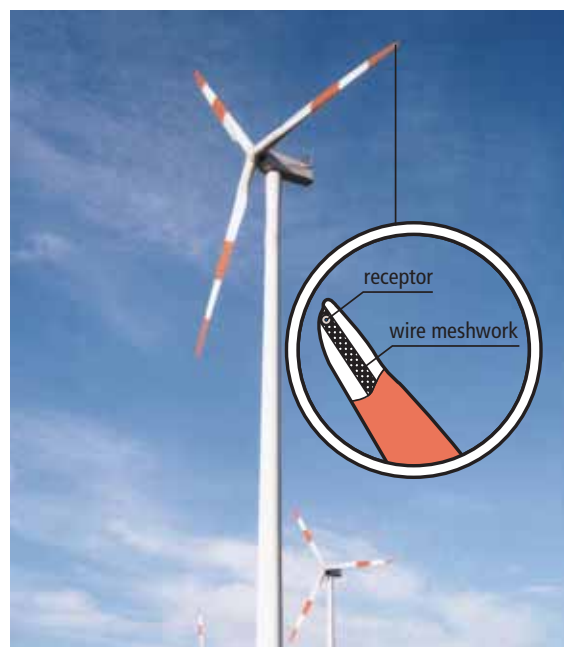


Fig. 5.1.10.1 WT with integrated receptors in the rotor blades



Fig. 5.1.10.2 Lightning protection for wind speed indicators at WT

In order to protect structures on the nacelle, such as anemometers in the event of a lightning strike, air-termination rods or “air-termination cages” are installed (**Figure 5.1.10.2**).

The metal tower or, in case of a prestressed concrete version, the down-conductor systems embedded in the concrete (round conductor St/tZn Ø 8 ...10 mm or tape conductor St/tZn 30 mm x 3.5 mm) is used as the down-conductor system. The wind turbine is earthed by a foundation earth electrode in the base of the tower and the meshed connection with the foundation earth electrode of the operation building. This creates an “equipotential surface” which prevents potential differences in the event of a lightning strike.

5.1.11 Wind load stresses on lightning protection air-termination rods

Roofs are used more and more as areas for technical installations. Especially when extending the technical equipment in the structure, extensive installations are sited more than ever on the roofs of larger office blocks and industrial structures. It is essential to protect roof-mounted structures such as air conditioning and cooling systems, transmitters for cell sites on host buildings, lamps, flue gas vents and other apparatus connected to the electrical low voltage system (**Figure 5.1.11.1**).

In accordance with the relevant lightning protection standards contained in the IEC 62305 (EN 62305) series, these roof-mounted structures can be protected from direct lightning strikes with isolated air-termination systems. This requires an iso-



Fig. 5.1.11.1 Protection against direct lightning strikes by self-supporting air-termination rods

lation of both the air-termination systems, such as air-termination rods, air-termination tips or air-termination meshes, and the down-conductor systems, i.e. to be installed with sufficient separation distance from the roof-mounted structures within the zone of protection. The construction of an isolated lightning protection system creates a zone of protection in which direct lightning strikes cannot occur. It also prevents partial lightning currents from entering the low voltage system and hence the structure. This is important as the entering of partial lightning currents into the building can affect or destroy sensitive electrical/electronic installations.

Extended roof-mounted structures are also equipped with a system of isolated air-termination systems. These are connected with each other and also with the earth-termination system. Among other things the magnitude of the zone of protection created depends on the number and the height of the air-termination systems installed.

A single air-termination rod is sufficient to provide the protection required by smaller roof-mounted structures. The procedure involves the application of the rolling sphere method in accordance with IEC 62305-3 (EN 62305-3) (**Figure 5.1.11.2**).

With the rolling sphere method, a rolling sphere whose radius depends on the class of lightning

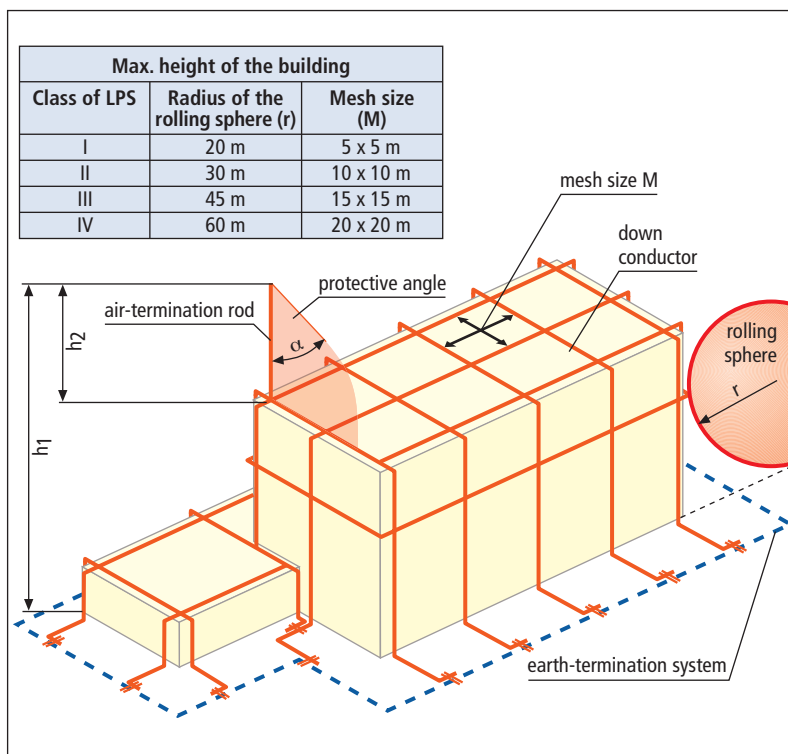


Fig. 5.1.11.2 Procedure for installation of air-termination systems according to IEC 62305-3 (EN 62305-3)

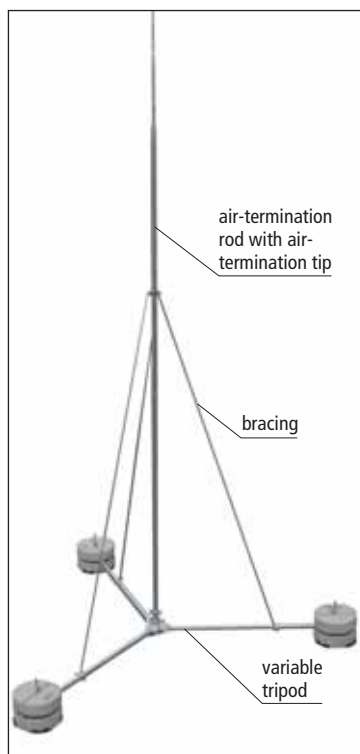


Fig. 5.1.11.3 Self-supporting air-termination rod with variable tripod

protection system chosen is rolled in all possible directions on and over the structure to be protected. During this procedure, the rolling sphere must touch the ground (reference plane) and/or the air-termination system only.

This method produces a protection volume where direct lightning strikes are not possible.

To achieve the largest possible volume of protection, and also to be able to protect larger roof-mounted structures against direct lightning strikes, the individual air-termination rods should ideally be erected with a corresponding height. To prevent self-supporting air-termination rods from tilting and breaking a suitably designed base and supplementary braces are required (**Figure 5.1.11.3**).

The requirement for the self-supporting air-termination rods to be built as high as possible must be balanced against the higher stress exerted by the active wind loads. A 40 % increase in wind speed, for example, doubles the active tilting moment. At the same time, from the application point of view,

users demand a lightweight system of "self-supporting air-termination rods", which are easier to transport and install. To ensure that it is safe to use air-termination rods on roofs, their mechanical stability must be proven.

Stress caused by wind loads

Since self-supporting air-termination rods are installed at exposed sites (e.g. on roofs), mechanical stresses arise which, owing to the comparable location and the upcoming wind speeds, correspond to the stresses suffered by antenna frames. Self-supporting air-termination rods must therefore basically meet the same requirements concerning their mechanical stability as set out in the German standard DIN 4131 for antenna frames. DIN 4131 divides Germany up into 4 wind zones with zone-dependent wind speeds (**Figure 5.1.11.4**).

When calculating the prospective actual wind load stresses, apart from the zone-dependent wind load, the height of the structure and the local con-

ditions (structure standing alone in open terrain or embedded in other buildings) must also be included. From **Figure 5.1.11.4** it can be seen that around 95 % of Germany's surface area lies within Wind Zones I and II. Air-termination rods are therefore generally designed for Wind Zone II. The use of self-supporting air-termination rods in Wind Zone III and Wind Zone IV must be assessed for each individual case taking the arising stresses into account.

According to DIN 4131 a constant dynamic pressure over the height of a structure can be expected for structures up to a height of 50 m. For the calculations, the maximum height of the structure was considered 40 m, so that a total height (height of the structure plus length of the air-termination rods) is kept below the 50 m mark.

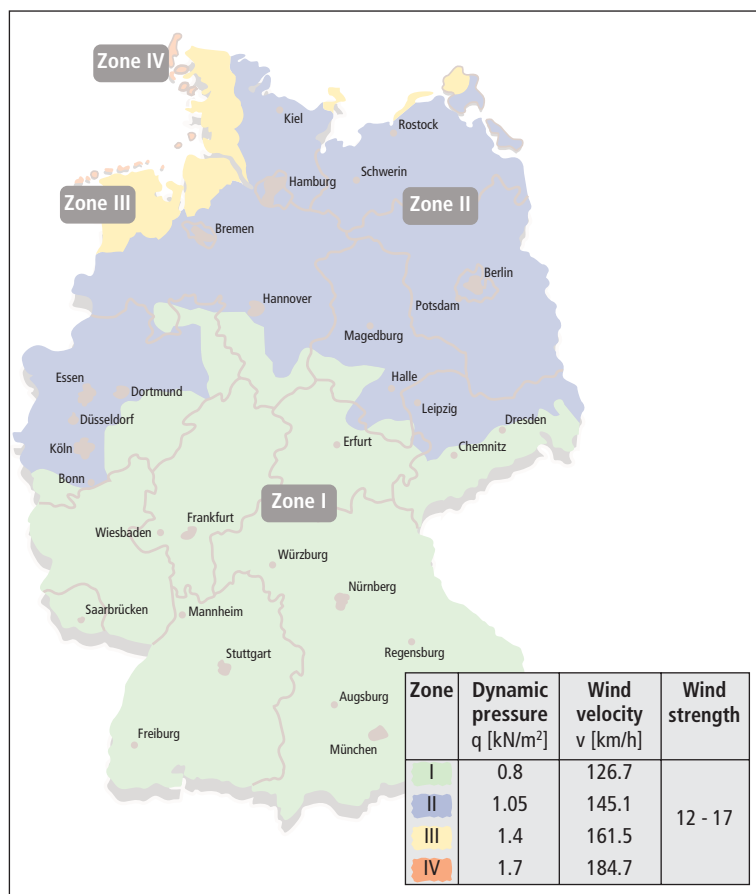


Fig. 5.1.11.4 Division of Germany into wind load zones and corresponding values of dynamic pressure and max. wind speed
Ref.: DIN 4131:1991-11: Steel antenna frames, Berlin: Beuth-Verlag, GmbH

When designing self-supporting air-termination rods, the following requirements must be met for the wind load stress:

- ⇒ Tilt resistance of the air-termination rods
- ⇒ Fracture resistance of the rods
- ⇒ Maintaining the required separation distance to the object to be protected even under wind loads (prevention of intolerable deflections)

Determination of the tilt resistance

The dynamic pressure arising (depends on the wind speed), the resistance coefficient c_w and the contact surface of the wind on the air-termination rod, generate a uniform load q' on the surface which generates a corresponding tilting moment M_T on the self-supporting air-termination rod. To

ensure that the self-supporting air-termination rod is stable, the tilting moment M_T must be opposed by a load torque M_O , which is generated by the post. The magnitude of the load torque M_O depends on the standing weight and the radius of the post. If the tilting moment is greater than the load torque, the wind load pushes the air-termination rod over.

The proof of the stability of self-supporting air-termination rods is also obtained from static calculations. Besides the mechanical characteristics of the materials used, the following information is included in the calculation:

- ⇒ **Wind contact surface of the air-termination rod:** determined by length and diameter of the individual sections of the air-termination rod.
- ⇒ **Wind contact surface of the bracing:** Very high self-supporting air-termination rods are anchored with 3 braces mounted equidistantly around the circumference. The wind contact surface of these braces corresponds to the area projected by these braces onto a plane in a right angle to the direction of the wind, i.e. the

brace lengths are shortened accordingly when considered in the calculation.

- ⇒ **Weight of the air-termination rod and the bracing:** The dead weight of the air-termination rod and the braces is taken into account in the calculation of the load torque.
- ⇒ **Weight of the post:** The post is a tripod weighted down with concrete blocks. The weight of this post is made up of the dead weight of the tripod and the individual weights of the concrete blocks used.
- ⇒ **Tilting lever of the post:** The tilting lever denotes the shortest distance between the centre of the tripod and the line or point around which the whole system would tilt.

The proof of stability is obtained by comparing the following moments:

- ⇒ **Tilting moment** formed from the wind-load-dependent force on the air-termination rod or the braces and the lever arm of the air-termination rod.
- ⇒ **Load torque** formed from the weight of the post, the weight of the air-termination rod and the braces, and the length of the tilt lever through the tripod.

Stability is achieved when the ratio of load torque to the tilting moment assumes a value >1 .

Basically: the greater the ratio of load torque to tilting moment, the greater the stability.

The required stability can be achieved in the following ways:

- ⇒ In order to keep the wind contact surface of the air-termination rod small, the cross sections used have to be as small as possible. The load on the air-termination rod is reduced, but, at the same time, the mechanical strength of the air-termination rod decreases (risk of breaking). It is therefore crucial to make a compromise between a smallest possible cross section to reduce the wind load and a largest possible cross section to achieve the required strength.
- ⇒ The stability can be increased by using larger base weights and/or larger post radii. This often conflicts with the limited areas for erection and the general requirement for low weight and easy transport.

Implementation

In order to provide the smallest possible wind contact surface, the cross sections of the air-termination rods were optimised in accordance with the results of the calculation. For easier transportation and installation, the air-termination rod comprises an aluminium tube (in sections, if so desired) and an aluminium air-termination rod. The post to hold the air-termination rod is hinged and is available in two versions. Roof pitches up to 10° can be compensated..

Determination of the fracture resistance

Not only the stability of the air-termination rod must be proven, but also the fracture resistance, since the occurring wind load exerts bending stresses on the self-supporting air-termination rod. The bending stress in such cases must not exceed the max. permissible stress. The bending stress occurring is higher for longer air-termination rods. The air-termination rods must be designed to ensure that wind loads as can arise in Wind Zone II cannot cause permanent deformation of the rods.

Since both the exact geometry of the air-termination rod and the non-linear performance of the materials used must be taken into account, the proof of the fracture resistance of self-supporting air-termination rods is obtained using an FEM calculation model. The finite elements method, FEM for short, is a numerical method for calculation of stresses and deformations of complex geometrical structures. The structure under examination is broken down into so-called "finite elements" using imaginary surfaces and lines which are interconnected via nodes.

The calculation requires the following information:

⇒ FEM-calculation model

The FEM calculation model corresponds to the simplified geometry of the self-supporting air-termination rod.

⇒ Material characteristics

The performance of the material is represented by the details of cross-sectional values, modulus of elasticity, density and lateral contraction.

⇒ Loads

The wind load is applied to the geometric model as a pressure load.

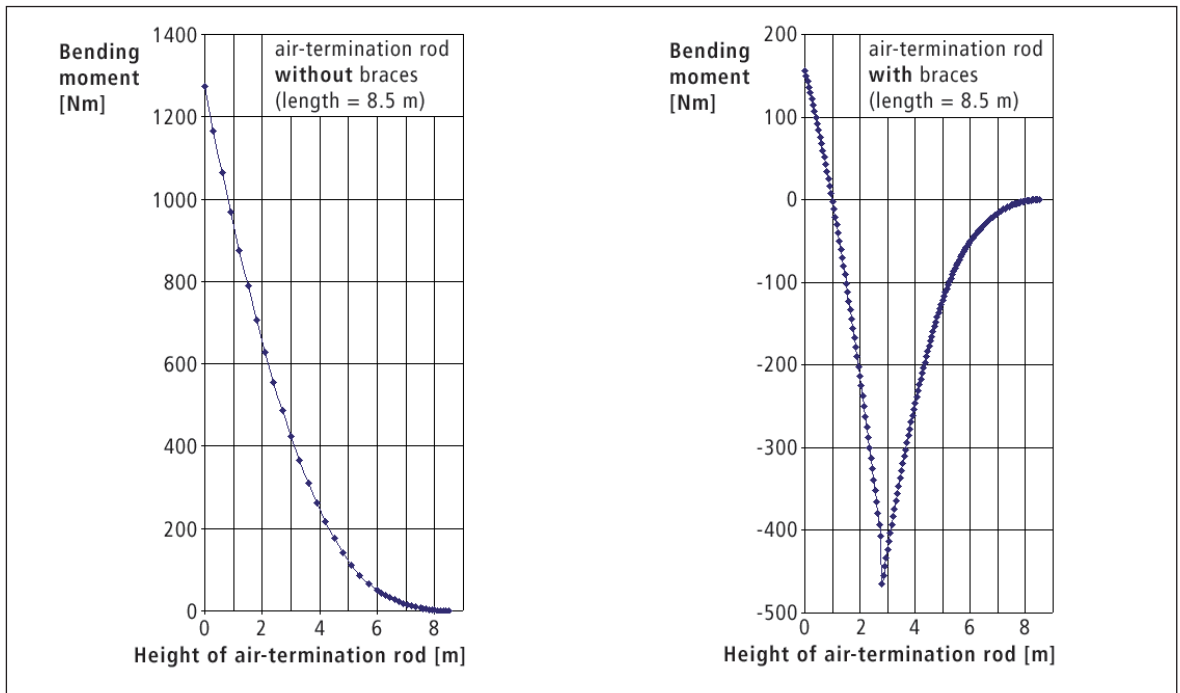


Fig. 5.1.11.5 Comparison of bending moment courses at self-supporting air-termination rods with and without braces (length = 8.5 m)

The fracture resistance is determined by comparing the permissible bending stress (material parameter) and the max. bending stress which can occur (calculated from the bending moment and the effective cross section at the point of maximum stress).

Fracture resistance is achieved if the ratio of permissible to actual bending stress is >1 . Basically, the same principle also applies here: the greater the ratio of permissible to actual bending stress, the greater the fracture resistance.

Using the FEM calculation model, the actual bending moments for two air-termination rods (length = 8.5 m) were calculated as a function of their height with and without braces (**Figure 5.1.11.5**). This clearly illustrates the effect of a possible brace on the course of the moments. Whereas the max. bending moment of the air-termination rod without a brace in the fixed-end point is around 1270 Nm, the brace reduces the bending moment to around 460 Nm. This brace makes it possible to reduce the stresses in the air-termination rod to such an extent that, for the max. expected wind loads, the strength of the materials used is not

exceeded and the air-termination rod is not destroyed.

Implementation

Braces create an additional “bearing point” which significantly reduces the bending stresses occurring in the air-termination rod. Without supplementary bracing, the air-termination rods would not cope with the stresses of Wind Zone II. Therefore, air-termination rods higher than 6 m are equipped with braces.

In addition to the bending moments, the FEM calculation also provides the tensile forces occurring in the bracing, whose strength must also be proven.

Determination of the wind-load-dependent deflection of the air-termination rod

A further important value calculated with the FEM model is the deflection of the tip of the air-termination rod. Wind loads cause the air-termination rods to bend. The bending of the rod results in a change to the volume to be protected. Objects to be protected are no longer situated in the zone of

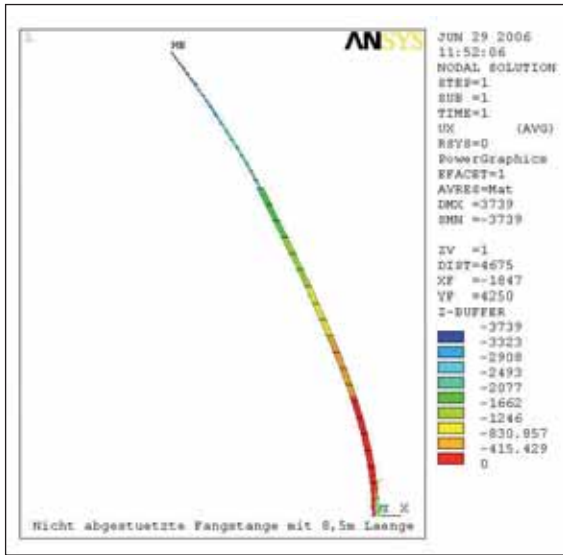


Fig. 5.1.11.6 FEM model of a self-supporting air-termination rod without bracing (length = 8.5 m)

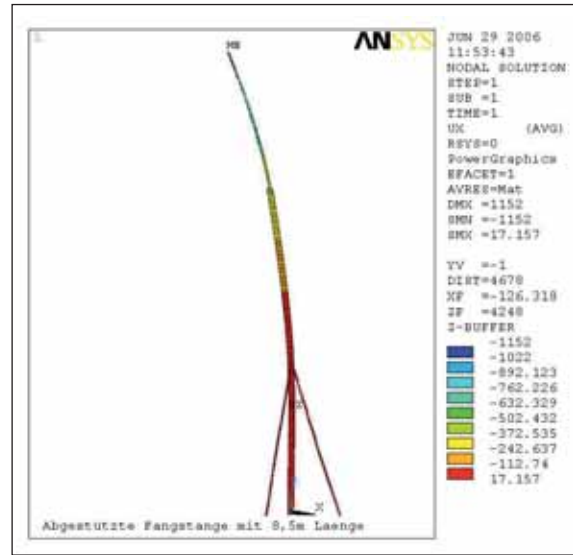


Fig. 5.1.11.7 FEM model of a self-supporting air-termination rod with bracing (length = 8.5 m)

protection and/or proximities can no longer be maintained.

The application of the calculation model on a self-supporting air-termination rod without and with braces produces the following results (**Figures 5.1.11.6 and 5.1.11.7**).

For the example chosen, the calculation gives a displacement of the tip of the air-termination rod with bracing of around 1150 mm. Without bracing there would be a deflection of around 3740 mm, a theoretical value which exceeds the breaking point of the air-termination rod under consideration.

Implementation

Above a certain rod height, supplementary braces reduce this deflection significantly. Furthermore, this also reduces the bending load on the rod.

Conclusion

Tilting resistance, fracture resistance and deflection are the decisive factors when designing air-termination rods. Base and air-termination rod must be coordinated to ensure that the loads occurring as a result of the wind speeds of Zone II do not cause a tilting of the rod, nor damage it. It must still be borne in mind that large deflections of the air-termination rod reduce the separation distance and thus intolerable proximities can arise.

Higher air-termination rods require a supplementary bracing to prevent such intolerable deflections of the tips of the air-termination rods.

The measures described ensure that self-supporting air-termination rods can cope with Zone II wind speeds according to DIN 4131 (German standard).

5.2 Down-conductor system

The down-conductor system is the electrically conductive connection between the air-termination system and the earth-termination system. The function of down-conductor systems is to conduct the intercepted lightning current to the earth-termination system without intolerable temperature rises, for example, to damage the structure.

To avoid damage caused during the lightning current discharge to the earth-termination system, the down-conductor systems must be mounted to ensure that from the point of strike to the earth,

- ⇒ several parallel current paths exist,
- ⇒ the length of the current paths is kept as short as possible (straight, vertical, no loops),
- ⇒ the connections to conductive components of the structure are made wherever required (distance < s; s = separation distance).

5.2.1 Determination of the number of down conductors

The number of down conductors depends on the perimeter of the external edges of the roof (perimeter of the projection on the ground surface).

The down conductors must be arranged to ensure that, starting at the corners of the structure, they are distributed as uniformly as possible to the perimeter.

Depending on the structural features (e.g. gates, precast components), the distances between the various down conductors can be different. In each case, there must be at least the total number of down conductor required for the respective class of lightning protection system.

The IEC 62305-3 (EN 62305-3) standard gives typical distances between down conductors and ring conductors for each class of lightning protection system (Table 5.2.1.1).

The exact number of down conductors can only be determined by calculating the separation distance s . If the calculated separation distance cannot be maintained for the intended number of down conductors of a structure, then one way of meeting this requirement is to increase the number of down conductors. The parallel current paths improve the current splitting coefficient k_c . This measure reduces the current in the down conductors, and the required separation distance can be maintained.

Natural components of the structure (e.g. reinforced concrete supports, steel skeleton) can also be used as supplementary down conductors if continuous electrical conductivity can be ensured.

By interconnecting the down conductors at ground level (base conductor) and using ring conductors for higher structures, it is possible to bal-

Class of LPS	Typical distance
I	10 m
II	10 m
III	15 m
IV	20 m

Table 5.2.1.1 Distance between down conductors according to IEC 62305-3 (EN 62305-3)

ance the distribution of the lightning current which, in turn, reduces the separation distance s .

The latest IEC 62305 (EN 62305) series of standards attaches great significance to the separation distance. The measures specified can change the separation distance positively for structures and thus the lightning current can be safely discharged.

If these measures are not sufficient to maintain the required separation distance, it is also possible to use a new type of high voltage-resistant isolated conductors (HVI). These are described in Chapter 5.2.4.

Chapter 5.6 describes how the exact separation distance can be determined.

5.2.2 Down-conductor system for a non-isolated lightning protection system

The down-conductor systems are primarily mounted directly onto the structure (with no distance). The criterion for installing them directly on the structure is the temperature rise in the event of lightning striking the lightning protection system. If the wall is made of flame-resistant material or material with a normal level of flammability, the down-conductor systems may be installed directly on or in the wall.

q mm ²	Ø	Type of lightning protection system											
		Aluminium			Iron			Copper			Stainless steel		
		III + IV	II	I	III + IV	II	I	III + IV	II	I	III + IV	II	I
16		146	454	*	1120	*	*	56	143	309	*	*	*
50	8 mm	12	28	52	37	96	211	5	12	22	190	460	940
78	10 mm	4	9	17	15	34	66	3	5	9	78	174	310
* melting / vaporising													

Table 5.2.2.1 Max. temperature rise ΔT in K of different conductor materials

Owing to the specifications in the building regulations of the German federal states, highly flammable materials are generally not used. This means that the down-conductor systems can usually be mounted directly on the structure.

Wood with a bulk density greater than 400 kg/m² and a thickness greater than 2 mm is considered to have a normal level of flammability. Hence the down-conductor system can be mounted on wooden poles, for example.

If the wall is made of highly flammable material, the down conductors can be installed directly on the surface of the wall, provided that the temperature rise when lightning currents flow is not hazardous.

The maximum temperature rise ΔT in K of the various conductors for each class of lightning protection system are stated in **Table 5.2.2.1**. These values mean that, generally, it is even permissible to install down conductors underneath heat insulation because these temperature rises present no fire risk to the insulation materials.

This ensures that the fire retardation measure is also provided.

When installing the down-conductor system in or underneath heat insulation, the temperature rise (on the surface) is reduced if an additional PVC sheath is used. Aluminium wire sheathed in PVC can also be used.

If the wall is made of highly flammable material, and the temperature rise of the down-conductor systems presents a hazard, then the down conductors must be mounted to ensure that the distance between the down-conductor systems and the wall is greater than 0.1 m. The mounting elements may touch the wall. The erector of the structure must state whether the wall, where a down-conductor system is to be installed, is made of flammable material.

In Germany the precise definition of the terms flame-resistant, normal level of flammability and highly flammable can be taken from Supplement 1 of DIN EN 62305-3 (VDE 0185-305-3).

5.2.2.1 Installation of down-conductor systems

The down conductors must be arranged to be the direct continuation of the air-termination conductors. They must be installed straight and vertically

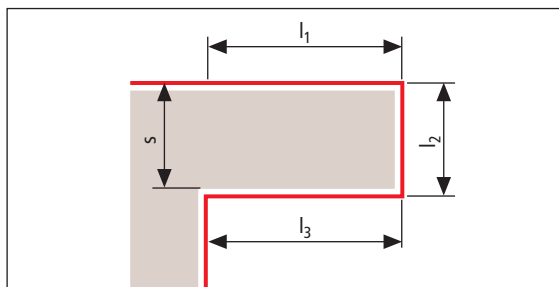


Fig. 5.2.2.1.1 Loop in the down conductor

so as to represent the shortest possible direct connection to the earth.

Loops, e.g. projecting eaves or structures, must be avoided. If this is not possible, the distance measured where two points of a down-conductor system are closest, and the length l of the down-conductor system between these points, must fulfill the requirements on the separation distance s (**Figure 5.2.2.1.1**).

The separation distance s is calculated using the total length $l = l_1 + l_2 + l_3$.

Down-conductor systems must not be installed in gutters and downpipes, even if they are sheathed in an insulating material. The damp in the gutters would badly corrode the down-conductor systems.

If aluminium is used as a down conductor, it must not be installed directly (with no distance) on, in or under plaster, mortar, concrete, neither should it be installed in the ground. If it is equipped with a PVC sheath, then aluminium can be installed in mortar, plaster or concrete, if it is possible to ensure that the sheath will not be mechanically damaged nor will the insulation fracture at low temperatures.

It is recommended to mount down conductors to maintain the required separation distance s to all doors and windows (**Figure 5.2.2.1.2**).

Metal gutters must be connected with the down conductors at the points where they intersect (**Figure 5.2.2.1.3**).

The base of metal downpipes must be connected to the equipotential bonding or the earth-termination system, even if the pipe is not used as a down conductor. Since it is connected to the eaves gutter, through which the lightning current flows, the downpipe also takes a part of the lightning

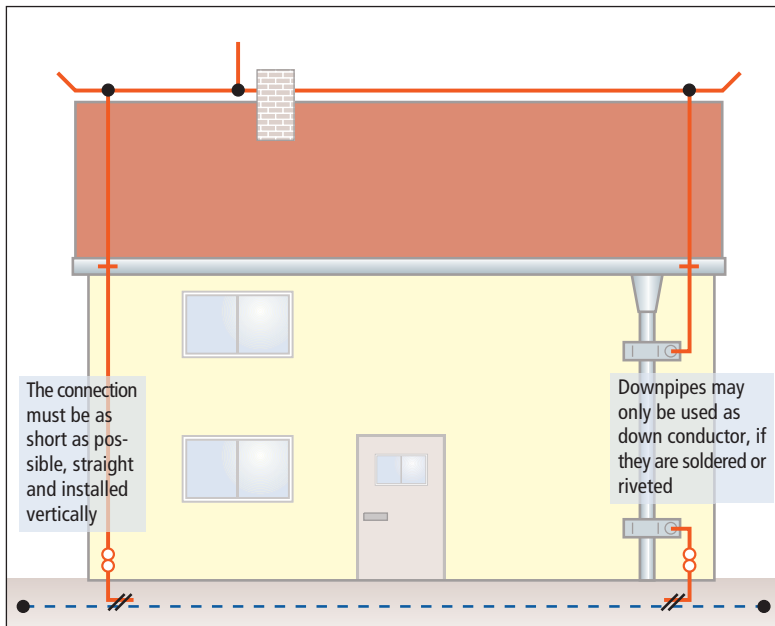


Fig. 5.2.2.1.2 Down-conductor system



Fig. 5.2.2.1.3 Air-termination system with connection to the gutter



Fig. 5.2.2.1.4 Earthed downpipe

current which must be conducted into the earth-termination system. **Figure 5.2.2.1.4** illustrates one possible design.

5.2.2.2 Natural components of a down-conductor system

When using natural components of the structure as a down-conductor system, the number of down conductors to be installed separately can be reduced or, in some cases, they can be dispensed with altogether.

The following parts of a structure can be used as "natural components" of the down-conductor system:

- ⇒ Metal installations, provided that the safe connection between the various parts is permanent and their dimensions conform to the minimum requirements for down conductors. These metal installations may also be sheathed in insulating material. The use of conduits containing flammable or explosive materials as down conductors is not permitted if the seals in the flanges/couplings are non-metallic or the flanges/couplings of the connected pipes

are not otherwise connected so as to be electrically conductive.

- ⇒ The metal skeleton of the structure

If the metal frame of structures with a steel skeleton or the interconnected reinforced steel of the structure is used as a down-conductor system, then ring conductors are not required since additional ring conductors would not improve the splitting of the current.

- ⇒ Safe interconnected reinforcement of the structure

The reinforcement of existing structures cannot be used as a natural component of the down-conductor system unless it can be ensured that the reinforcement is safely interconnected. Separate external down conductors must be installed.

- ⇒ Precast parts

Precast parts must be designed to provide terminal connections for the reinforcement. Precast parts must have an electrically conductive connection between all terminal connections. The individual components must be interconnected on site during installation (**Figure 5.2.2.2.1**).

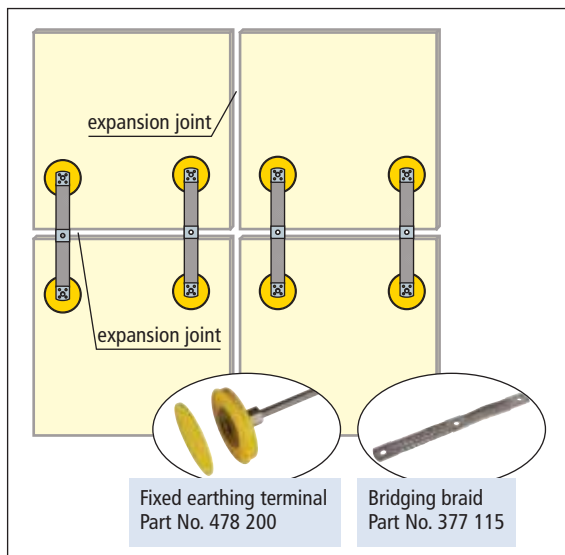


Fig. 5.2.2.2.1 Use of natural components – new buildings made of ready-mix concrete

Note:

In the case of prestressed concrete, attention must be paid to the particular risk of possible intolerable mechanical effects arising from lightning current and resulting from the connection to the lightning protection system.

For prestressed concrete, connections to tensioning rods or cables must only be effected outside the stressed area. The permission of the person responsible for erecting the structure must be given before using tensioning rods or cables as a down conductor.

If the reinforcement of existing structures is not safely interconnected, it cannot be used as a down-conductor system. In this case, external down conductors must be installed.

Furthermore, facade elements, mounting channels and the metal substructures of facades can be used as a natural down-conductor system, provided that:

- ⇒ the dimensions meet the minimum requirements of down-conductor systems. For sheet metal, the thickness must not be less than 0.5 mm. Their electrical conductivity in vertical direction must be ensured. If metal facades are used as a down-conductor system, they must be interconnected to ensure that the individual plates are safely interconnected with each

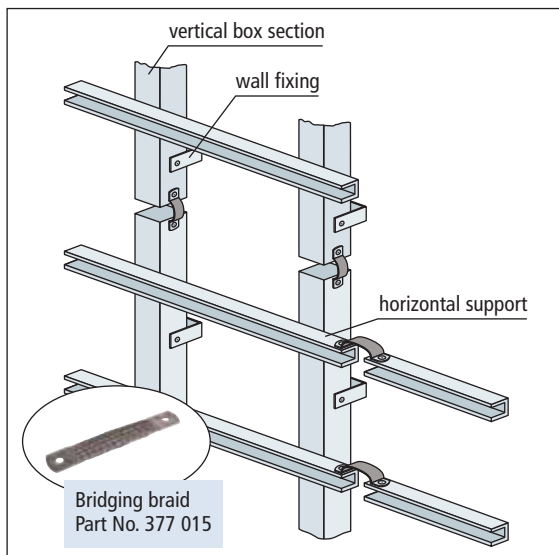


Fig. 5.2.2.2.2 Metal subconstruction, conductively bridged

other by means of screws, rivets, or bridging connections. There must be a safe connection capable of carrying currents to the air-termination system and also to the earth-termination system.

- ⇒ If metal plates are not interconnected in accordance with the above requirement, but the substructure ensures that they are continuously conductive from the connection on the air-termination system to the connection on the earth-termination system, then they can be used as a down-conductor system (**Figures 5.2.2.2.2 and 5.2.2.2.3**).



Fig. 5.2.2.2.3 Earth connection of a metal facade

Metal downpipes can be used as natural down conductors, as long as they are safely interconnected (brazed or riveted joints) and comply with the minimum wall thickness of the pipe of 0.5 mm. If a downpipe is not safely interconnected, it can serve as a holder for the supplementary down conductor. This type of application is illustrated in **Figure 5.2.2.2.4**. The connection of the downpipe to the earth-termination system must be capable of carrying lightning currents since the conductor is held only along the pipe.



Fig. 5.2.2.2.4 Down conductor installed along a downpipe



Fig. 5.2.2.3.1 Measuring point with number plate

5.2.2.3 Measuring points

There must be a measuring point at every connection of a down conductor with the earth-termination system (above the lead-in, if possible).

Measuring points are required to allow the inspection of the following characteristics of the lightning protection system:

- ⇒ Connections of the down conductors via the air-termination systems to the next down conductor
- ⇒ Interconnections of the terminal lugs via the earth-termination system, e.g. in the case of ring or foundation earth electrodes (earth electrode Type B)
- ⇒ Earth electrode resistance of single earth electrodes (earth electrode Type A)

Measuring points are not required if the structural design (e.g. reinforced concrete structure or steel skeleton) allows no "electrical" disconnection of the "natural" down-conductor system to the earth-termination system (e.g. foundation earth electrode).

The measuring point may only be opened with the help of a tool for the purpose of taking measurements, otherwise it must be closed.

Each measuring point must be able to be clearly assigned to the design of the lightning protection system. Generally, all measuring points are marked with numbers (**Figure 5.2.2.3.1**).

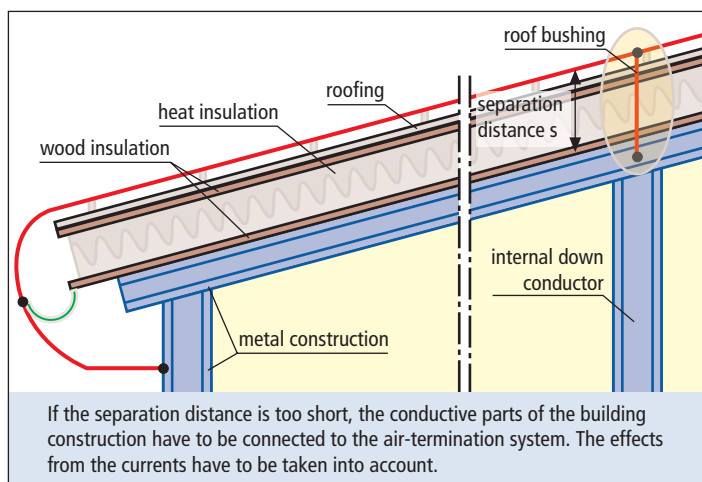


Fig. 5.2.2.4.1 Air-termination system installed on large roofs – Internal down-conductor system

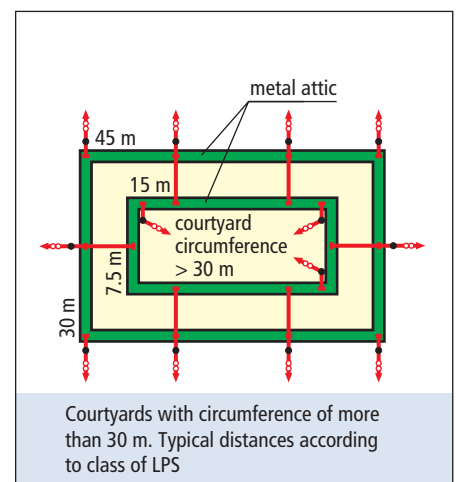


Fig. 5.2.2.5.1 Down-conductor systems for courtyards

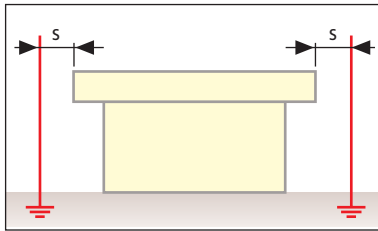


Fig. 5.2.3.1 Air-termination masts isolated from the building

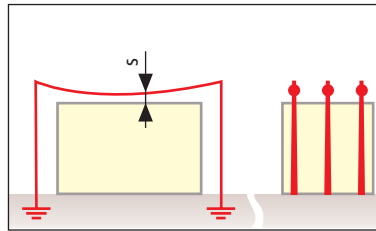


Fig. 5.2.3.2 Air-termination masts spanned with cables

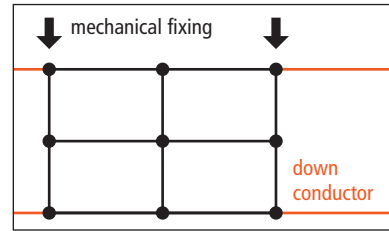


Fig. 5.2.3.3 Air-termination masts spanned with cables with cross connection (meshing)

5.2.2.4 Internal down-conductor systems

If the edges of the structure (length and width) are four times as large as the distance of the down conductors which corresponds to the class of lightning protection system, then supplementary internal down conductors must be installed (Figure 5.2.2.4.1).

The grid dimension for the internal down-conductor systems is around 40 m x 40 m.

Large structures with flat roofs, such as large production halls or also distribution centres, frequently require internal down conductors. In such cases, the ducts through the surface of the roof should be installed by a roofer because he is responsible for ensuring that the roof provides protection against rain.

The consequences of the partial lightning currents through internal down-conductor systems within the structure must be taken into account. The resulting electromagnetic field in the vicinity of the down conductor must be taken into consideration when designing the internal lightning protection system (pay attention to inputs to electrical/electronic systems.)

5.2.2.5 Courtyards

Structures with enclosed courtyards having a perimeter greater than 30 m (Figure 5.2.2.5.1) must have down-conductor systems installed with the distances shown in Table 5.2.1.1.

5.2.3 Down conductors of an isolated external lightning protection system

If an air-termination system comprises air-termination rods on isolated masts (or one mast), then this

is both air-termination system and down-conductor system at the same time (Figure 5.2.3.1).

Each individual mast requires at least one down conductor. Steel masts or mast with an interconnected steel reinforcement require no supplementary down-conductor system.

For optical reasons, a metal flag pole, for example can also be used as an air-termination system.

The separation distance s between the air-termination and down-conductor systems and the structure must be maintained.

If the air-termination system consists of one or more spanned wires or cables, each end of the cable which the conductors are attached to requires at least one down conductor (Figure 5.2.3.2).

If the air-termination system forms an intermeshed network of conductors, i.e. the individual spanned wires or cables are interconnected to form a mesh (being cross-linked), there must be at least one down conductor at the end of each cable the conductors are attached to (Figure 5.2.3.3).

5.2.4 High voltage-resistant, isolated down-conductor system – HVI conductor

A multitude of structures is used in order to create an exhaustive network of cell sites. Some of these structures have lightning protection systems. In order to design and implement the mast infrastructure in accordance with the standards, the actual situation must be taken into account during the design phase while the relevant standards have to be strictly differentiated.

For the operator of a mobile phone network there are basically **three different situations**:

- ⇒ Structure has no lightning protection system
- ⇒ Structure is equipped with a lightning protection system which is no longer capable of functioning
- ⇒ Structure is equipped with a functioning lightning protection system

Structure has no lightning protection system

In Germany cell sites are constructed in accordance with DIN VDE 0855-300. This deals with the earthing of the cell site. In accordance with the concept for protection against surges of the mobile phone network operators, supplementary protection against surges is integrated into the meter section.

Structure is equipped with a lightning protection system which is no longer capable of functioning

In Germany cell sites are connected to the external lightning protection system as required by the class of lightning protection system (LPS) determined. The lightning current paths required for the cell site are investigated and assessed. This involves replacing non-functional components of the existing installation which are required to discharge the lightning current, such as air-termination conductor, down-conductor system and connection to the earth-termination system. Any observed defects to parts of the installation which are not required must be notified in writing to the owner of the structure.

Structure is equipped with a functioning lightning protection system

Experience has shown that most lightning protection systems are designed according to LPS Class III. Regular inspections are prescribed for certain structures. It must be planned to integrate the cell site installation in accordance with the class of lightning protection system (LPS) determined. For installations with LPS Class I and II, the surroundings of the installation must be recorded photographically to ensure that, if problems subsequently arise with proximities, the situation at the time of construction can be proven. If a cell site is erected on a structure with a functional external lightning protection system, its erection is governed by the latest lightning protection standard (IEC 62305 (EN 62305)). In this case for example, in Germany the DIN VDE 0855-300 can only be used for the equipotential bonding of the antenna cable. Proximities must be calculated as appropriate to the

class of LPS. All mechanical components used must be able to cope with the prospective partial lightning currents. For reasons of standardisation, all the steel fixing elements and structures for holding antennas of many mobile phone network operators must be designed for LPS Class I. The connection should be done via the shortest route, which is not a problem, however, as the air-termination conductors on flat roofs are usually designed to be meshed. If there is a functional lightning protection system on the host building, this has a higher priority than an antenna earthing installation.

Because of how it is designed, the class of lightning protection system to be effected must be laid down at the discussion stage of the project:

- ⇒ If the system technology components are also situated on the roof, it is preferable to install the electrical cable on the exterior side of the structure.
- ⇒ If the system technology components are situated on the roof, and if it is intended to erect a central mast, the installation must be equipped with an isolated lightning protection system.
- ⇒ If the system technology components are located within the structure, it is preferable to have an isolated lightning protection embedment. Care must be taken that the cell site infrastructure is designed to be geometrically small so that the costs of the isolated lightning protection system are economically viable.

Experience has shown that, in many cases, existing lightning protection systems have old defects which adversely affect the effectiveness of the installation. These defects mean that even if the cell site is correctly "tied-in" to the external lightning protection system, damage can still be caused within the structure.

In order to enable a designer of mobile phone networks to erect antenna installations in accordance with the standards even in difficult situations, the only thing available to him used to be the isolated lightning protection system with horizontal distance holders. In such cases, however, the design of the antenna installation, could really not be considered architecturally aesthetic (**Figure 5.2.4.1**).



5.2.4.1



5.2.4.2

Fig. 5.2.4.1 Isolated air-termination system with distance holder

Fig. 5.2.4.2 Isolated air-termination system for cell sites –
Application of DEHNconductor system

Air-termination systems as shown in **Figure 5.2.4.1** are not applicable for locations where the antennas have to be pleasing to look at.

The isolated HVI conductor is an innovative solution which provides the installer of lightning protection systems with novel possibilities for design and for easy maintaining of the separation distance (**Figure 5.2.4.2**).

5.2.4.1 Installation and performance of the isolated down-conductor system HVI

Basic conception of the isolated down-conductor system is to cover the lightning current carrying conductor with an insulating material, allowing the necessary separation distance s to other conductive parts of the structure, to electrical conductors and conduits to be kept. Incorrect proximities must be avoided. Basically the following requirements to the isolated down-conductor system have to be met, if insulating materials are used to avoid inadmissible proximities:

- ⇒ Possibility of a lightning current proof connection of the down-conductor system with the air-termination system (air-termination rod, air-termination conductor, air-termination tip, etc.) by terminals.

- ⇒ Compliance with the required separation distance s by sufficient dielectric strength of the down-conductor system in the range of the input point as well as in the course of the down-conductor system.
- ⇒ Sufficient current carrying capability because of an adequate cross section of the down-conductor system.
- ⇒ Possibility of connection to the earth-termination system or of equipotential bonding.

Sheathing of the down conductors with insulating materials of high dielectric strength basically allows to reduce the separation distance. Certain high voltage technological requirements, however, have to be met. This being necessary as the dielectric strength of the isolated down-conductor system depends on its positioning and on the occurrence of creeping discharges.

The use of unshielded, isolated down-conductor systems is a fundamental solution to be independent with regard to positioning and laying. A conductor, however, which has only a sheathing of insulating material does not solve the problem. Already relatively low induced impulse voltages will release creeping discharges in the range of the proximities (e.g. between metal, earthed conductor holders and the feeding point), which can result in a total flashover at the surface of long conductor sections. Ranges of insulating material, metal (at high voltage potential or earthed) getting in contact with the air are critical with regard to creeping discharges. This range is subject to a high voltage stressing because of the potential arising of creeping discharges, resulting in a considerably reduced voltage resistance. Creeping discharges have to be taken into account, whenever usual (vertical to the surface of the insulating material) components of electrical field strength E , lead to the tripping voltage of the creeping discharge being exceeded and, field components tangentially enforce the increase of creeping discharges (**Figure 5.2.4.1.1**).

The creeping discharge release-voltage determines the resistance of the whole insulation, being in the magnitude of 250 – 300 kV lightning impulse voltage.

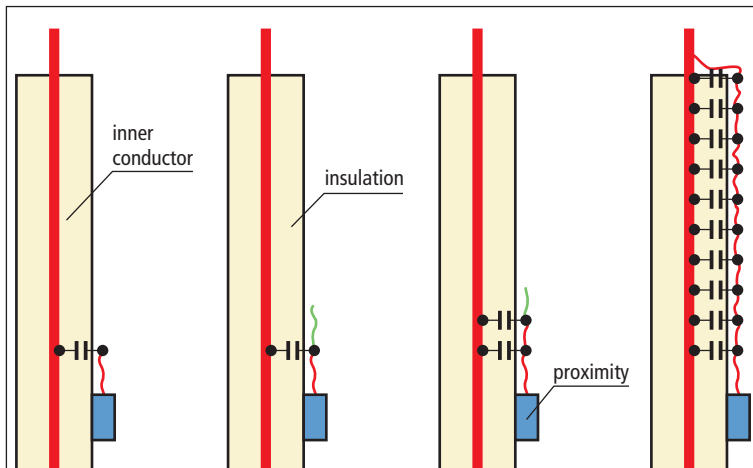


Fig. 5.2.4.1.1 Basic development of a creeping discharge at an isolated down conductor without special coating

By the coaxial single conductor cable – HVI conductor – shown in **Figure 5.2.4.1.2** the occurrence of the creeping discharge is avoided and the lightning current is safely conducted to the earth.

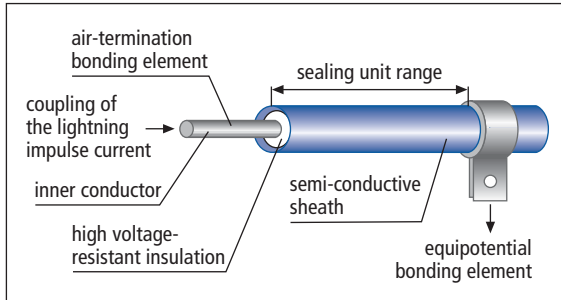


Fig. 5.2.4.1.2 Components of HVI Conductor



Fig. 5.2.4.1.3 HVI conductor I and components of the DEHNconductor system

Isolated down-conductor systems with field control and semi-conductive shield prevent from creeping discharges by a targeted influencing of the electric field in the range of the input point. They allow the lightning current to be conducted into the special cable, the safe discharge of the lightning current and the required separation distance s to be kept. The semi-conductive shield of the coaxial input cable insulates from the electric field. It has to be minded, however, that the magnetic field surrounding the current carrying inner conductor is not affected.

Optimisation of the field control allows an adjusted cable sealing unit length of 1.50 m to realise the

required equivalent separation distance in air of $s \leq 0.75$ m and in case of solid construction material of $s \leq 1.50$ m (**Figure 5.2.4.1.3**).

This special cable sealing unit is realised by an adjusted connection element to the air-termination system (supply point) and the equipotential bonding terminal in a fixed distance. Compared with a coaxial cable with metal shield, the whole semi-conductive coating of the cable has a clearly higher resistance. Even by a multiple equipotential bonding connection of the cable coating only insignificant partial lightning currents will be dragged into the building.

Apart from the required separation distance s , the maximum conductor length L_{\max} of such an isolated down-conductor system is calculated with

$$L_{\max} = \frac{k_m \cdot s}{k_i \cdot k_c}$$

5.2.4.2 Installation examples

Application for cell sites

Cell site installations are frequently erected on host structures. There is usually an agreement between the operator of the cell site installation and the owner of the structure that the erection of the cell site installation must not increase the risk

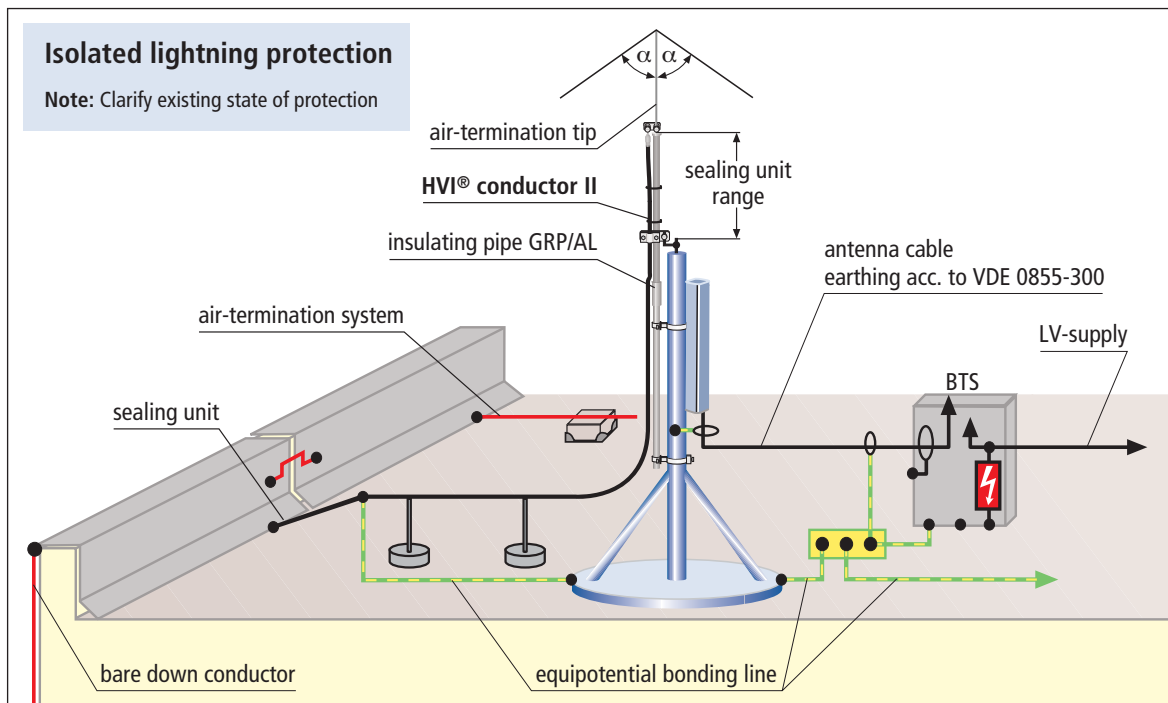


Fig. 5.2.4.2.1 Integration of a new 2G/3G antenna into the existing lightning protection system by using the HVI conductor

to the structure. For protection against lightning, this particularly means that no partial lightning currents must enter the structure if there is a lightning strike to the frame structure. A partial lightning current within the structure would especially put the electrical and electronic apparatus at risk.

Figure 5.2.4.2.1 shows one possible solution for the “isolated air-termination system” on the frame structure of an antenna. The air-termination tip must be fixed to the frame structure of the antenna by means of an insulating pipe in non conductive material so that it is isolated. The height of the air-termination tip is governed by the requirement that the structure of the frame and any electrical devices which are part of the cell site installation (BTS – Base Transceiver Station) must be arranged in the zone of protection of the air-termination tip.

Structures with several antenna systems must be equipped with multiple “isolated air-termination systems”.

Figures 5.2.4.2.2a and b illustrate the installation on an antenna post.

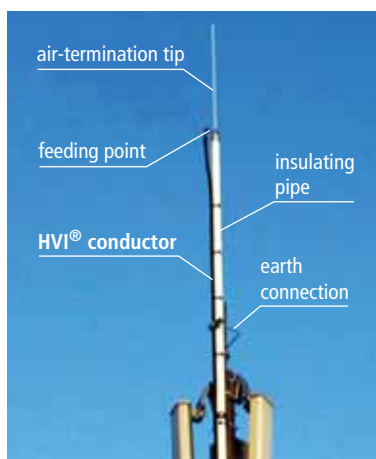


Fig. 5.2.4.2.2a Insulating pipe within the antenna area

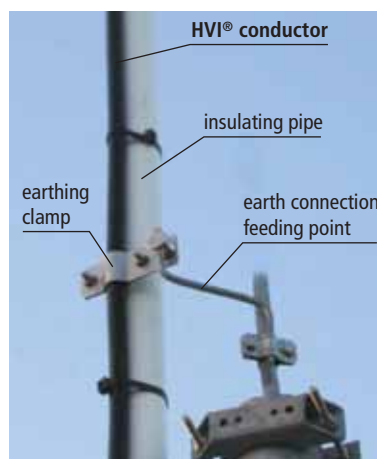


Fig. 5.2.4.2.2b Connection to the antenna frame structure for directing potential



Fig. 5.2.4.2.3a Fan with air-termination rod and spanned cable



Fig. 5.2.4.2.3b Air-termination rod, elevated ring conductor connected to the isolated down-conductor system

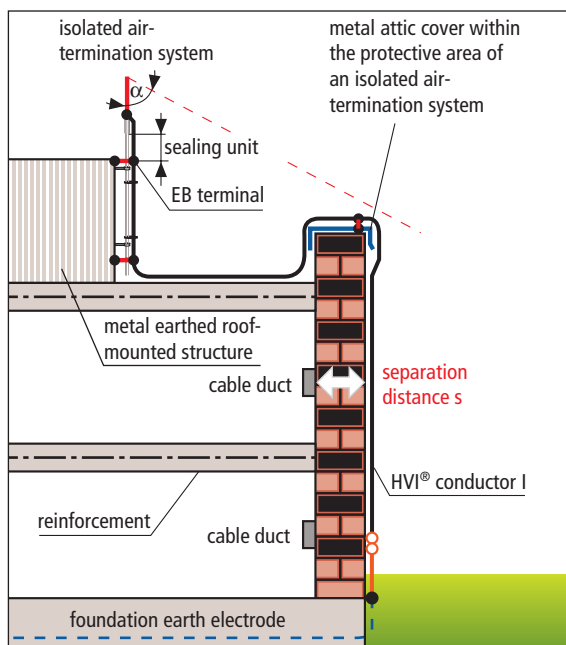


Fig. 5.2.4.2.4 Keeping the required separation distance with voltage-controlled isolated down conductor (HVI)

Roof-mounted structures

Metal and electrical roof-mounted structures protrude above roof level and are exposed points for lightning strikes. The risk of partial lightning currents flowing within the structure is also existing because of conductive connections with conduits and electrical conductors leading into the structure. To prevent this and to set up the necessary separation distance for the complete structure easily, the air-termination system must be installed with a terminal to the isolated down-conductor system, as shown in **Figure 5.2.4.2.3a** and **5.2.4.2.3b**.

Hence all metal and electrical roof-mounted structures protruding above roof level are within the area protected against lightning strikes. The lightning current will be “channeled” along the structure and distributed by the earth-termination system.

If several structures are mounted on the roof then, according to the basic illustration in **Figure 5.2.4.2.4**, several isolated air-termination systems must be installed. This must be done to ensure that all structures protruding above the roof must be arranged in an area protected from lightning strikes (lightning protection zone LPZ 0_B).

Down-conductor system

Especially problematical from the optical point of view often is the integration of a down-conductor system, taking into account the required separation distance s .

The HVI conductor e.g. can be installed or even integrated in the facade (**Figure 5.2.4.2.5**). This new kind of isolated down-conductor system con-

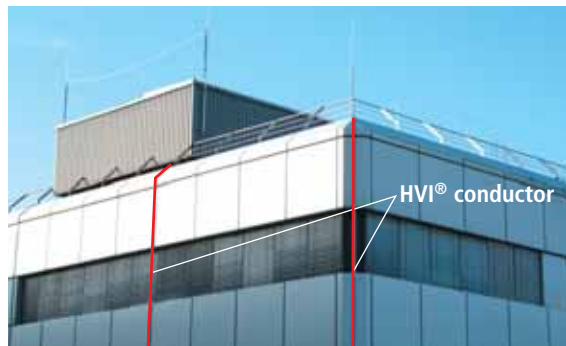


Fig. 5.2.4.2.5 Air termination system with spanned cable and isolated down-conductor system

tributes to an architectural more pleasing structure. Functionality and design can be an entity. Therefore this innovative technology is an important feature of modern architecture.

5.2.4.3 Project example: Training and residential building

Structure

The structure in **Figure 5.2.4.3.1** was built conventionally from the ground floor to the 6th floor. At a later date, the 7th floor was attached to the existing roof surface.

The external facade of the 7th floor consists of metal sheets.

The media centre is situated on the 3rd floor, the ground floor is used for administration. All other floors up to the 7th floor are used for apartments. The roof surface of the 6th and 7th floor was finished off with a metal attic whose components are interconnected so as to be non-conductive.

The complete structure is 25.80 m high (without attic) up to the roof level.

Subsequently, five antenna systems for mobile phone systems and microwaves were installed by different operators of mobile phone networks on the roof surface of the 7th floor. The antennas were erected both in the corners and in the middle of the roof surface.

The cable (coax cables) from the four antennas in the corners of the roof surface were installed in the vicinity of the attic to the south-west corner. From this point, the cables are led through a metal cable duct which is connected to the attic of the roof surfaces of the 7th and 6th floors to the BTS room on the 6th floor.

The cables from the antenna in the middle are also installed by means of a metal cable duct directly to the 2nd BTS room on the north-east side of the structure to the 6th floor. This cable duct is also connected to the surrounding attics.

The structure was equipped with a lightning protection system. The new installation of the external lightning protection system to protect against damage to the structure and life hazards was designed in accordance with the national lightning protection stan-

dard DIN V VDE V 0185-3, which was applicable when the building was erected.

During the installation of the antennas, the equipotential bonding and earthing measures of the system were carried out in accordance with the German standard DIN VDE 0855 Part 300.

The earthing of the systems, however, was not isolated from the existing external lightning protection system at the earth-termination system at ground level, but directly at the air-termination system.

Hence, in the event of a lightning discharge, partial lightning currents are conducted directly into the structure via the coax cable shields. These partial lightning currents do not only present a life hazard, they also present a hazard to the existing technical equipment of the structure.

New concept

A lightning protection system was required, which prevents partial lightning currents from being conducted directly into the structure via the antenna components (frame structures, cable shields and installation systems). At the same time, the required separation distance s between the frame structures of the antennas and the air-termination system on the roof surface of the 7th floor must be realised.

This cannot be effected with a lightning protection system of a conventional design.

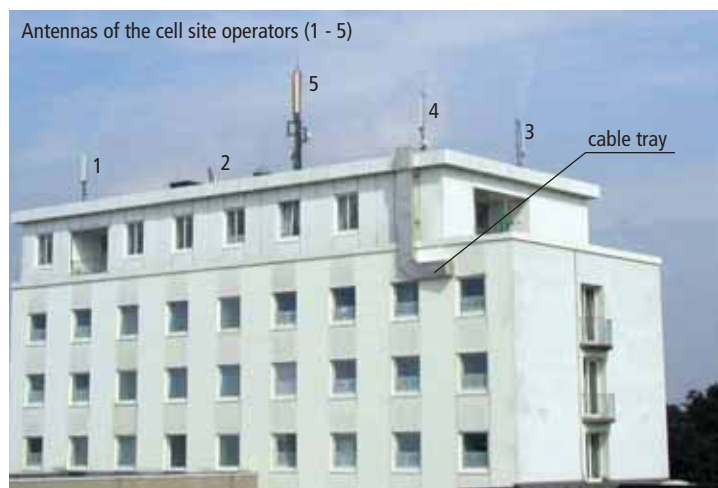


Fig. 5.2.4.3.1 Total view

By installing the HVI conductor, a lightning protection system was constructed with an isolated air-termination system. This required the following components:

- ⇒ Air-termination tips on insulating pipes in GRP material, secured directly to the antenna pole (**Figure 5.2.4.2.2a**).
- ⇒ Down conductor from the air-termination tip by means of an HVI conductor with connection to the isolated ring conductor (**Figure 5.2.4.3.2**).
- ⇒ Sealing end feeding point to ensure the resistance against creeping flashovers at the input (**Figures 5.2.4.2.2a and 5.2.4.2.2b**).
- ⇒ Isolated ring conductor on insulating supports made of GRP, supports as high as according to the calculation of the required separation distance
- ⇒ Down conductors installed separately from the isolated ring conductor via the respective metal attics and metal facade to the bare metal down conductors on the 6th floor with the required separation distance s to the lower attic (**Figure 5.2.4.3.3**).
- ⇒ Supplementary ring conductor, all down-conductor systems interconnected at a height of approx. 15 m to reduce the required separation distance s of the interception and down-conductor system (**Figures 5.2.4.3.4 and 5.2.4.4.1**).

The various implementation stages explained in detail are summarised in **Figure 5.2.4.3.4**.

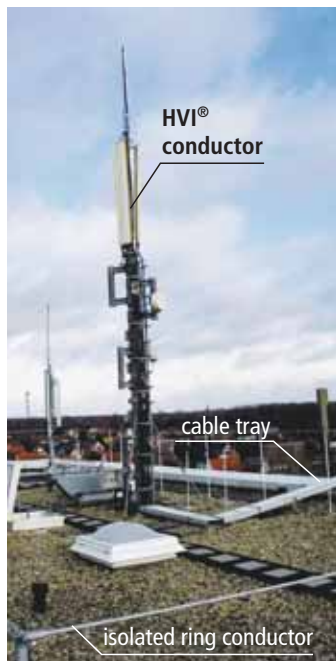


Fig. 5.2.4.3.2 Isolated air-termination system and isolated ring conductor
Ref.: H. Bartels GmbH, Oldenburg, Germany

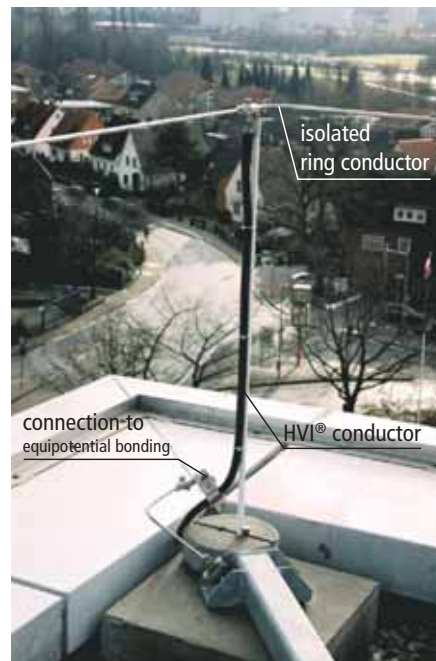


Fig. 5.2.4.3.3 Down conductor of isolated ring conductor

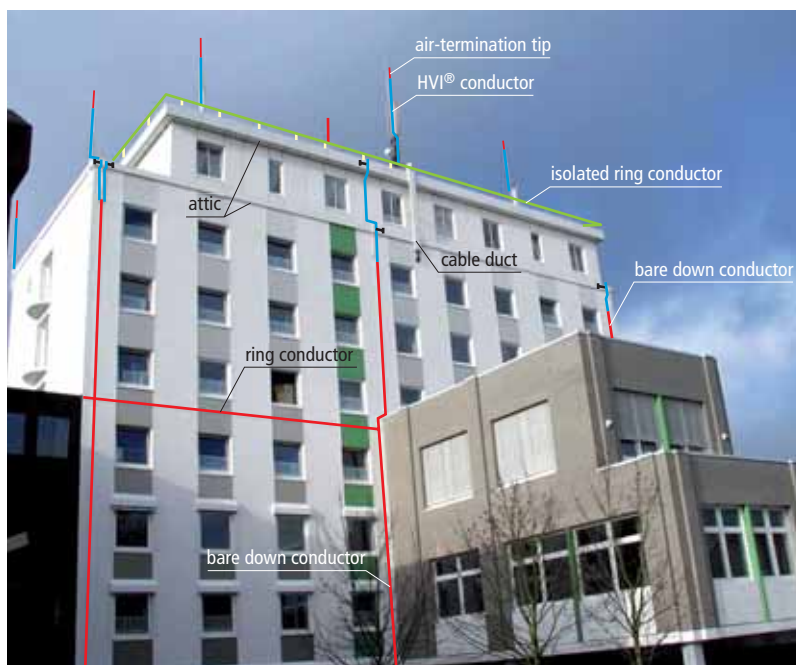


Fig. 5.2.4.3.4 Total view on a newly installed external lightning protection system

It is also important to note that the proposed design concept was discussed in detail with the system erector in order to avoid mistakes when carrying out the work.

When designing the external lightning protection system, care was taken that the deck on the 6th floor (Figure 5.2.4.3.1) and the lower attachments (Figure 5.2.4.3.4) were also arranged in the zone of protection/protective angle of the air-termination system.

5.2.4.4 Separation distance

When calculating the required separation distance s , not only the height of the structure but also the heights of the individual antennas with the isolated air-termination system had to be taken into consideration.

Each of the four corner antennas protrudes 3.6 m above the surface of the roof. The antenna in the middle protrudes 6.6 m above the roof surface.

Considering the height of the structure, result the following total heights to be taken into account when calculating the installation:

⇒ 4 corner antennas to the base of the air-termination tip + 29.40 m

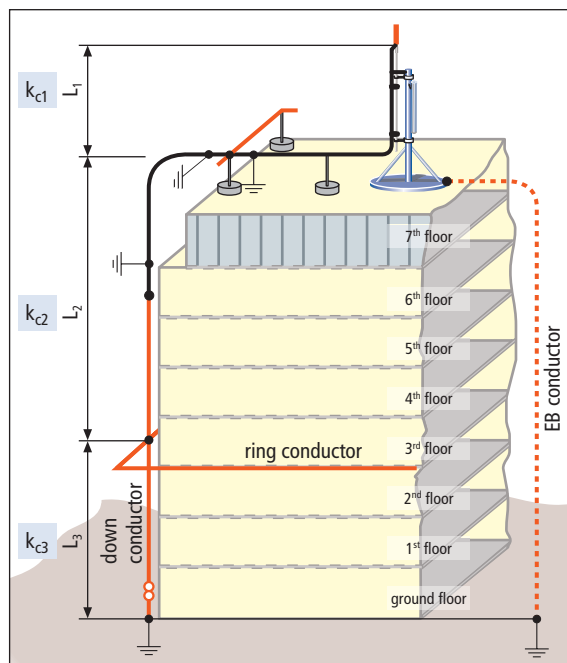


Fig. 5.2.4.4.1 Calculation of the required separation distance

- ⇒ 1 antenna in the middle of the roof surface to the base of the air-termination tip + 32.40 m
- ⇒ Three further, isolated separate air-termination rods on the west side of the roof surface and two isolated air-termination masts on the balcony 6th floor, south side, realise the zone of protection of the complete roof surface.

A special cable, DEHNconductor, Type HVI, was used as the isolated down conductor, allowing an equivalent separation distance of $s = 0.75$ m (air)/1.5 m (solid building materials) to be maintained.

The calculation of the required separation distances was done as shown in Figure 5.2.4.4.1 for three partial areas:

1. Partial area at a level of + 32.4 m and a level of + 29.4 m (antennas) to + 27.3 m (isolated ring conductor) on the roof.
2. Partial area at + 27.3 m to + 15.0 m (isolated ring conductor on roof up to lower supplementary ring conductor).
3. Partial area at + 15.0 to ± 0 m (lower ring conductor to ground level).

The complete down-conductor system comprises six down conductors from the isolated ring conductor at a height of + 27.3 m to the supplementary ring conductor at a level of + 15.0 m. The ring conductor at a level of + 15.0 m is connected with the earthing ring conductor via the six down conductors of the residential structure and four further down conductors on attached parts of the structure.

This produces a different splitting of the current in the individual partial areas which had to be taken into consideration for the design of the lightning protection system.

The equipotential bonding required and the earthing of the antenna components on the roof surface (including the cable ducts, metal facades and the attics on both roof levels) was done using two supplementary earthing cables NYY 1 x 25 mm² connected to the equipotential bonding of the individual BTS stations.

The erection of this isolated air-termination system on the surface of the roof and on the antenna systems, as well as the isolated down conductors around metal parts of the structure, prevent partial lightning currents from entering the structure.

Material	Configuration	Min. cross-section mm ²	Remarks ¹⁰⁾
Copper	solid flat material solid round material ⁷⁾ cable solid round material ^{3), 4)}	50 ⁸⁾ 50 ⁸⁾ 50 ⁸⁾ 200 ⁸⁾	min. thickness 2 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Tin plated copper ¹⁾	solid flat material solid round material ⁷⁾ cable	50 ⁸⁾ 50 ⁸⁾ 50 ⁸⁾	min. thickness 2 mm diameter 8 mm min. diameter each wire 1.7 mm
Aluminium	solid flat material solid round material cable	70 50 ⁸⁾ 50 ⁸⁾	min. thickness 3 mm diameter 8 mm min. diameter each wire 1.7 mm
Aluminium alloy	solid flat material solid round material cable solid round material ³⁾	50 ⁸⁾ 50 50 ⁸⁾ 200 ⁸⁾	min. thickness 2.5 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Hot dipped galvanised steel ²⁾	solid flat material solid round material ⁹⁾ cable solid round material ^{3), 4), 9)}	50 ⁸⁾ 50 50 ⁸⁾ 200 ⁸⁾	min. thickness 2.5 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Stainless steel ⁵⁾	solid flat material ⁶⁾ solid round material ⁶⁾ cable solid round material ^{3), 4)}	50 ⁸⁾ 50 70 ⁸⁾ 200 ⁸⁾	min. thickness 2 mm min. thickness 8 mm min. diameter each wire 1.7 mm diameter 16 mm

1) Hot dipped or electroplated, minimum thickness of the coating 1 µm.

2) The coating should be smooth, continuous and free of residual flux, minimum thickness 50 µm.

3) For air-termination rods. For applications where mechanical loads, like wind loads are not critical, a max. 1 m long air-termination rod with a diameter of 10 mm with an additional fixing may be used.

4) For lead-in earth rods.

5) Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0.03 %

6) For stainless steel in concrete and/or in direct contact with flammable material, the min. cross section for solid round material has to be increased to 78 mm² (10 mm diameter) and for solid flat material to 75 mm² (3 mm thickness).

7) For certain applications where the mechanical strength is not important, 28 mm² (6 mm diameter) material may be used instead of 50 mm² (8 mm diameter). Then distance of the fixing elements has to be reduced.

8) If thermal and mechanical requirements are important, the min. cross section for solid flat material can be increased to 60 mm² and for solid round material to 78 mm².

9) At a specific energy of 10,000 kJ/Ω the min. cross section to prevent from melting is 16 mm² (copper), 25 mm² (aluminium), 50 mm² (steel) and 50 mm² (stainless steel). For further information see Annex E.

10) Thickness, width and diameter are defined at a tolerance of ± 10 %.

Table 5.3.1 Material, configuration and min. cross sections of air-termination conductors, air-termination rods and down conductors according to IEC 62305-3 (EN 62305-3) Table 6

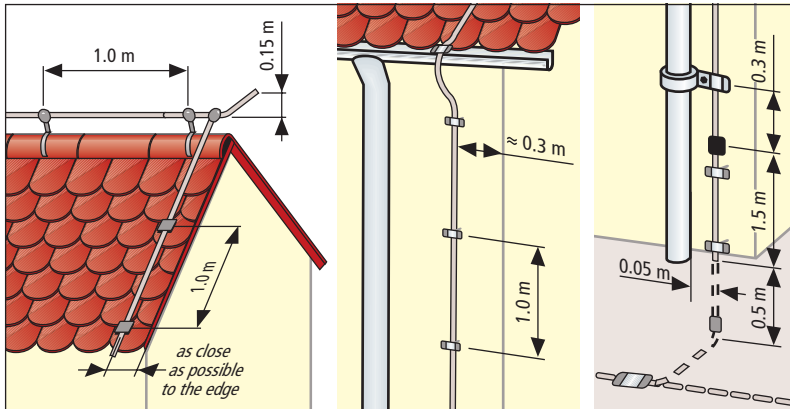


Fig. 5.4.1 Detail examples of an external lightning protection system at a building with a sloped tiled roof

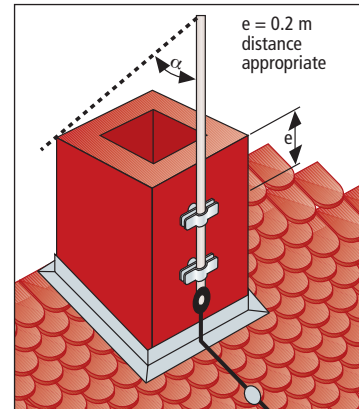


Fig. 5.4.2 Air-termination rod for chimneys

5.3 Materials and minimum dimensions for air-termination conductors and down conductors

Table 5.3.1 gives the minimum cross sections, form and material of air-termination systems.

These requirements arise from the electrical conductivity of the materials to carry lightning currents (temperature rise) and the mechanical stresses when in use.

When using a round conductor $\varnothing 8$ mm as an air-termination tip, the max. free height permitted is 0.5 m. The height limit for a round conductor $\varnothing 10$ mm is 1 m in free length.

Note:

According to IEC 62305-3 (EN 62305-3) Clause 1, Table 8, the minimum cross section for an interconnecting conductor between two equipotential bonding bars is 14 mm² Cu.

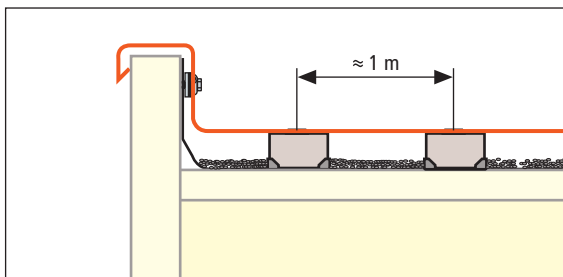


Fig. 5.4.3 Application on a flat roof

Tests with a PVC-insulated copper conductor and an impulse current of 100 kA (10/350 μ s) determined a temperature rise of around 56 K. Thus, a cable NYY 1 x 16 mm² Cu can be used as a down conductor or as a surface and underground interconnecting cable, for example.

5.4 Assembly dimensions for air-termination and down-conductor systems

The following dimensions (Figure 5.4.1) have been tried and tested in practice and are primarily determined by the mechanical forces acting on the components of the external lightning protection system.

These mechanical forces arise not so much as a result of the electrodynamic forces generated by the lightning currents, but more as a result of the compression forces and the tensile forces, e.g. due to temperature-dependent changes in length, wind loads or the weight of snow.

The information concerning the max. distances of 1.2 m between the conductor holders primarily relates to St/tZn (relatively rigid). For using aluminium, distances of 1 m have become the standard in practice.

IEC 62305-3 (EN 62305-3) gives the following assembly dimensions for an external lightning protection system (Figures 5.4.1 and 5.4.2).

Figure 5.4.3 illustrates the application on a flat roof.

If possible, the separation distance to windows, doors and other openings should be maintained when installing down conductors.

Further important assembly dimensions are illustrated in **Figures 5.4.3 – 5.4.5**.

Installation of surface earth electrodes (e.g. ring earth electrodes) around the structure at a depth of > 0.5 m and a distance of approx. 1 m from the structure (**Figure 5.4.4**).

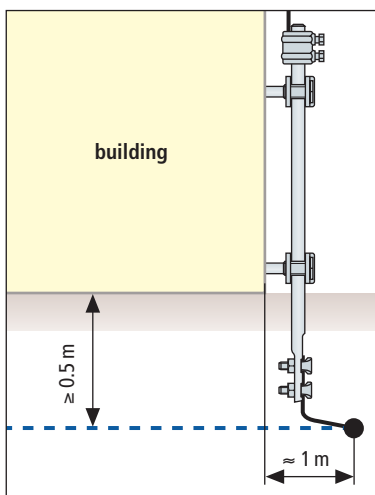


Fig. 5.4.4 Dimensions for ring earth electrodes

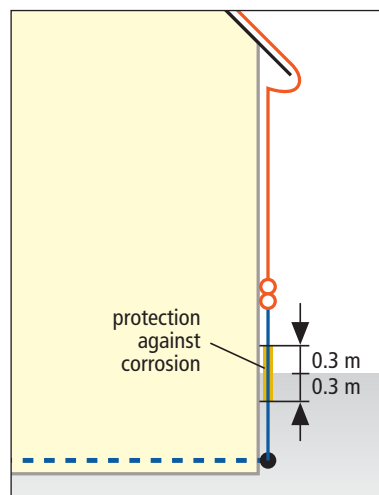


Fig. 5.4.5 Points threatened by corrosion

For the earth entries or terminals on the foundation earth electrode (ring earth electrodes), corrosion protection must be considered. Measures such as anticorrosive bands or wires with PVC sheath at a min. of 0.3 m above and below the turf (earth entry) must be employed (**Figure 5.4.5**) for protection.

An optically acceptable and noncorrosive connection possibility is provided by a stainless steel fixed earthing terminal set to be laid in concrete. Moreover, there must also be corrosion protection for the terminal lug for equipotential bonding inside the building in damp and wet rooms.

The material combinations below (within air-termination systems, down conductors and with parts of the structure) have been tried and tested, provided that no particularly corrosive environmental conditions must be taken into consideration. These are values obtained from experience (**Table 5.4.1**).

5.4.1 Change in length of metal wires

In practice, the temperature-dependent changes in length of air-termination and down conductors are often underestimated.

The older regulations and stipulations recommended an expansion piece about every 20 m as a general rule in many cases. This stipulation was based on the use of steel wires, which used to be the usual and sole material employed. The higher values for the coefficients of linear expansion of stainless steel, copper and especially aluminium materials were not taken into account.

In the course of the year, temperature changes of 100 K must be expected on and around the roof. The resulting changes in length for different metal wire materials are shown in **Table 5.4.1.1**. It is noticeable that, for steel and aluminium, the tem-

	Steel (tZn)	Aluminium	Copper	StSt	Titanium	Tin
Steel (tZn)	yes	yes	no	yes	yes	yes
Aluminium	yes	yes	no	yes	yes	yes
Copper	no	no	yes	yes	no	yes
StSt	yes	yes	yes	yes	yes	yes
Titanium	yes	yes	no	yes	yes	yes
Tin	yes	yes	yes	yes	yes	yes

Table 5.4.1 Material combinations

Material	Coefficient of linear expansion α	ΔL Calculation formula $\Delta L = \alpha \cdot L \cdot \Delta T$ Assumed temperature change on the roof: $\Delta T = 100 \text{ K}$
	$\frac{1}{10^6} \frac{1}{\text{K}}$	
Steel	11.5	$\Delta L = 11.5 \cdot 10^{-6} \cdot 100 \text{ cm} \cdot 100 = 0.115 \text{ cm} = 1.1 \text{ mm/m}$
StSt	16	$\Delta L = 16 \cdot 10^{-6} \cdot 100 \text{ cm} \cdot 100 = 0.16 \text{ cm} = 1.6 \text{ mm/m}$
Copper	17	$\Delta L = 17 \cdot 10^{-6} \cdot 100 \text{ cm} \cdot 100 = 0.17 \text{ cm} = 1.7 \text{ mm/m}$
Aluminium	23.5	$\Delta L = 23.5 \cdot 10^{-6} \cdot 100 \text{ cm} \cdot 100 = 0.235 \text{ cm} = 2.3 \text{ mm/m}$

Table 5.4.1.1 Calculation of the temperature-related change in length ΔL of metal wires in lightning protection



Fig. 5.4.1.1 Air-termination system – Compensation of expansion with bridging braid

Material	Surface under the fixing of the air-termination system or down conductor		Distance of expansion pieces in m
	soft, e. g. flat roof with bitumen- or synthetic roof sheetings	hard, e. g. pantiles or brickwork	
Steel	X		≈ 15
		X	≤ 20
StSt/Copper	X		≈ 10
		X	≤ 15
Aluminium	X	X	≤ 10
Use of expansion pieces, if no other length compensation is provided			

Table 5.4.1.2 Expansion pieces in lightning protection – Recommended application

perature-dependent changes in length differ by a factor of 2.

The stipulations governing the use of expansion parts in practice are thus as shown in **Table 5.4.1.2**. When using pieces, care must be taken that they provide flexible length equalisation. It is not sufficient to bend the metal wires into an S shape since these “expansion pieces”, handmade on site, are not sufficiently flexible.

When connecting air-termination systems, for example to metal attics surrounding the edges of roofs, care should be taken that there is a flexible connection to suitable components or measures. If this flexible connection is not made, there is a risk that the metal attic cover will be damaged by the temperature-dependent change in length.

To compensate for the temperature-dependent changes in length of the air-termination conductors, expansion pieces must be used to equalise the expansion (**Figure 5.4.1.1**).

5.4.2 External lightning protection system for an industrial structure and a residential house

Figure 5.4.2.1a illustrates the design of the external lightning protection system for a residential house with attached garage and **Figure 5.4.2.1b** that for an industrial structure.

Figures 5.4.2.1a and **5.4.2.1b** and **Tables 5.4.2.1a** and **b** show examples of the components in use today.

No account is taken of the measures required for an internal lightning protection system such as lightning equipotential bonding and surge protection (see also Chapter 6).

Particular attention is drawn to DEHN’s DEHNSnap and DEHNgrip programme of holders.

The DEHNSnap generation of synthetic holders (**Figure 5.4.2.2**) is suitable as a basic component

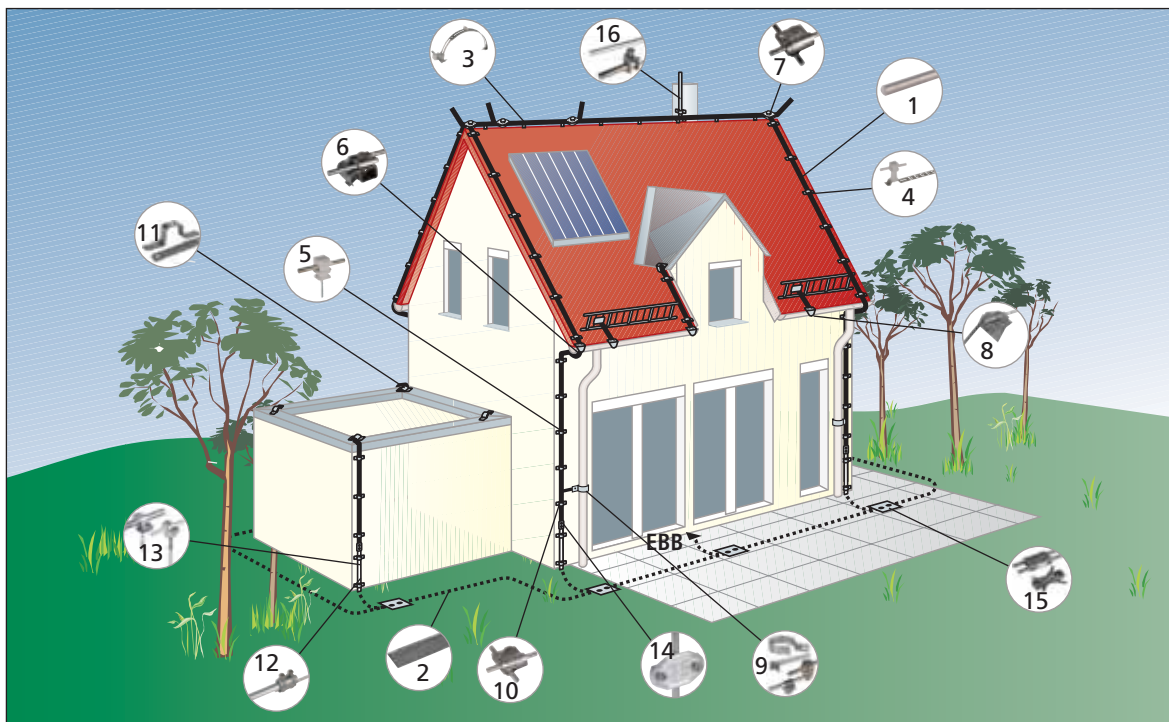


Fig. 5.4.2.1a External lightning protection of a residential building

Pos.	Part description	Part No.	Pos.	Part description	Part No.
1	Round conductor \varnothing 8 mm - DEHNALU, medium hard soft- twistable	840 008 840 018	7	MV clamp MV clamp	St/tZn 390 050 StSt 390 059
2	Steel strip 30 x 3.5 mm Round conductor \varnothing 10 mm	St/tZn 810 335 StSt V4A 860 010	8	Gutter board clamp	St/tZn 343 000
3	Roof conductor holders for ridge and hip tiles	St/tZn 202 020 StSt 204 109 StSt 204 249 StSt 204 269 StSt 206 109 StSt 206 239	9	Downpipe clamp adjustable for \varnothing 60 - 150 mm Downpipe clamp for any cross sections KS connector for connecting conductors KS connector	423 020 423 200 301 000 StSt 301 009
4	Roof conductor holders for conductors within roof surfaces	StSt 204 149 StSt 204 179 St/tZn 202 010 St/tZn 202 050 St/tZn 202 080 StSt 206 209 St/tZn 206 309	10	MV clamp	390 051
5	DEHNSnap DEHNgrrip conductor holder with cleat and flange conductor holder for heat insulation	204 006 207 009 275 160 273 740	11	Bridging bracket Bridging braid	Aluminium 377 006 Aluminium 377 015
6	Gutter clamp for beads Single-screw gutter clamp	St/tZn 339 050 StSt 339 059 St/tZn 339 100 StSt 339 109	12	Lead-in earthing rod \varnothing 16 mm complete	480 150 480 175
			13	Rod holder with cleat and flange Rod holder for heat insulation	275 260 273 730
			14	Number plate for marking isolating points	480 006 480 005
			15	Parallel connector Cross unit SV clamps SV clamps	305 000 306 020 319 201 St/tZn 308 220 StSt 308 229
			16	Air-termination rod with forged tab Air-termination rod with rounded ends Rod clamp	100 075 483 075 380 020

Table 5.4.2.1a Components for external lightning protection of a residential building

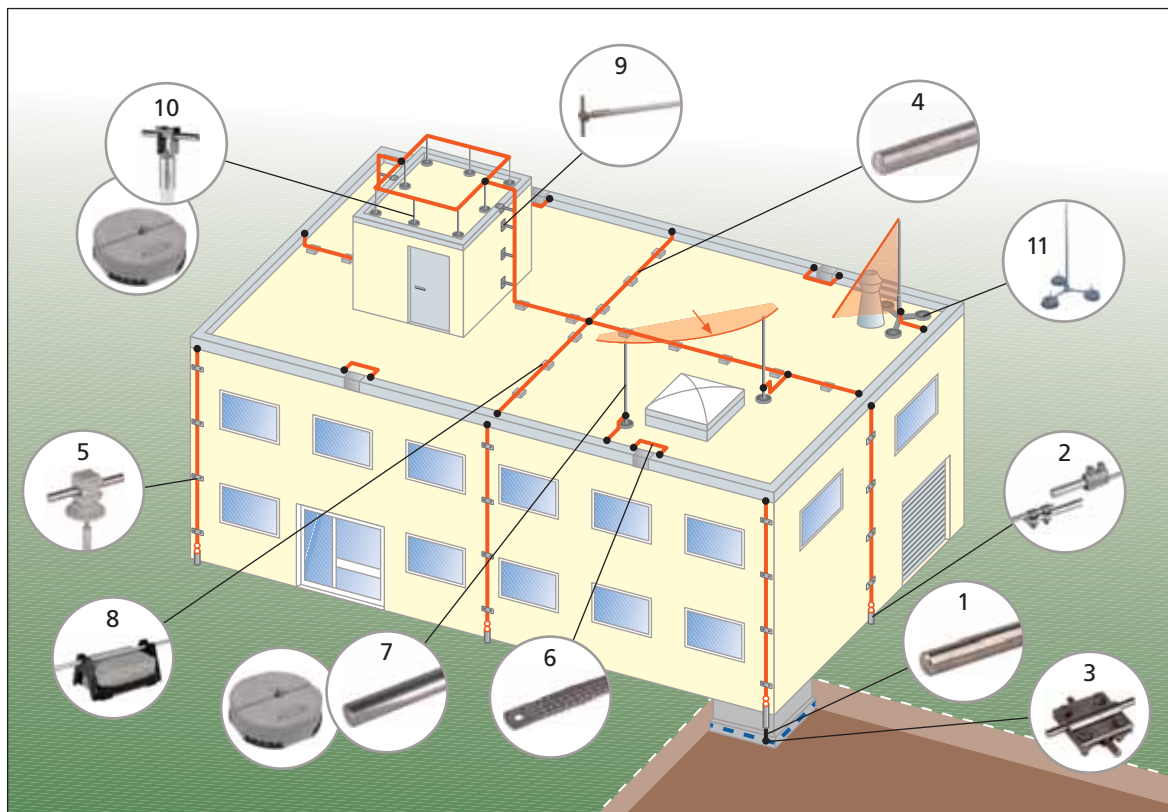


Fig. 5.4.2.1b External lightning protection of an industrial structure

Pos.	Part description	Part No.	Pos.	Part description	Part No.
1	Stainless steel conductor \varnothing 10 mm	StSt 860 010	8	Roof conductor holder for flat roofs	253 050
2	Set of lead-in earthing rods	St/tZn 480 150	9	DEHNiso distance holder	ZDC-St/tZn 106 100
3	Cross unit	StSt 319 209	10	Elevated ring conductor with concrete base with adapted flat washer and distance holder	StSt 102 340 106 160
4	DEHNALU-DRAHT®	AlMgSi 840 008	11	Isolated air-termination rod	105 500
5	Conductor holder DEHNSnap®	204 120			
6	Bridging braid	Al 377 015			
7	Air-termination rod with concrete base with adapted flat washer	AlMgSi 104 200 120 340			

Table 5.4.2.1b Components for external lightning protection of a residential structure

(roof and wall). The cap simply snaps in to fix the conductor in the holder while still being loosely guided. The special snap-in technique exerts no mechanical load on the fastening.

DEHNgrip (Figure 5.4.2.2) is a stainless steel system of holders without screws which was put into the

programme to supplement the DEHNSnap system of synthetic holders.

This system of holders without screws can also be used as both a roof and a wall conductor holder for \varnothing 8 mm conductors.

Simply press in the conductors and the conductor is fixed in DEHNgrip (Figure 5.4.2.2).

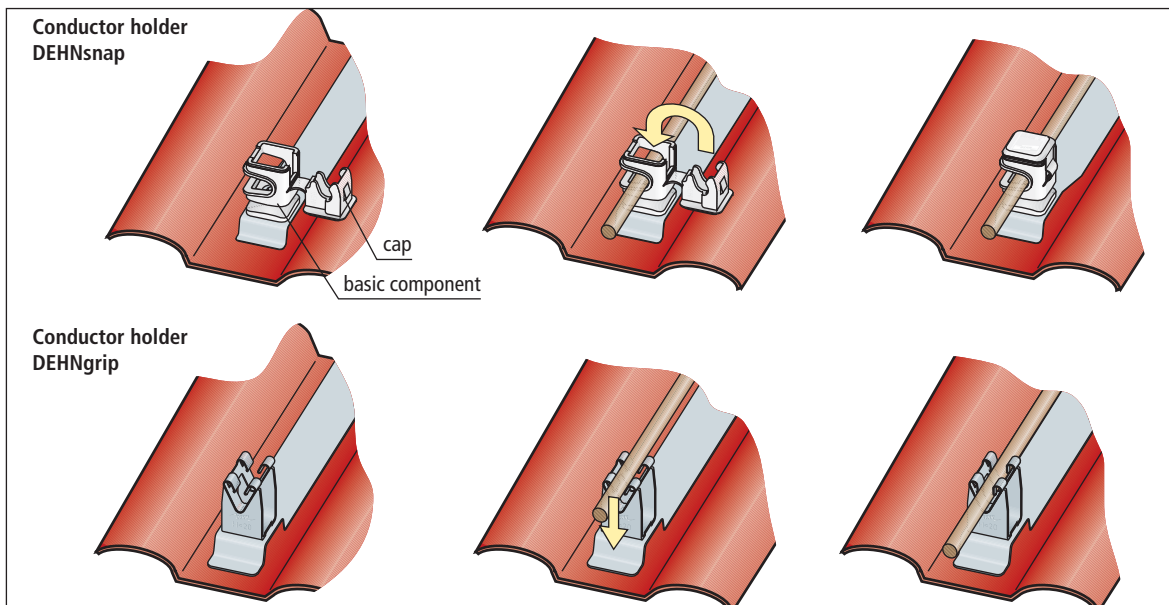


Fig. 5.4.2.2 DEHNSnap and DEHNgrip conductor holders

5.4.3 Application tips for mounting roof conductors holders

Ridge and hip tiles:

Adjust roof conductor holders with adjusting screw to suit the dimension of the ridge tile (Figure 5.4.3.1).

The conductor leading can, in addition, be gradually adjusted by means of conductor holders from the top centre to the bottom side.

(Conductor holder can be loosened by either turning the holder or opening the fixing screw.)

⇒ SPANNsnap roof conductor holder with DEHNSnap synthetic conductor holder or DEHNgrip stainless steel conductor holder (Figure 5.4.3.2).

Permanent tension due to stainless steel tension spring. Universal tension range from

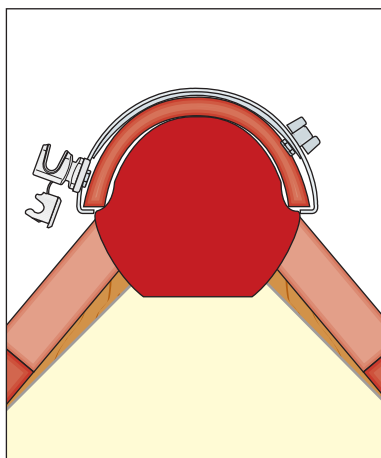


Fig. 5.4.3.1 Conductor holder with DEHNSnap for ridge tiles

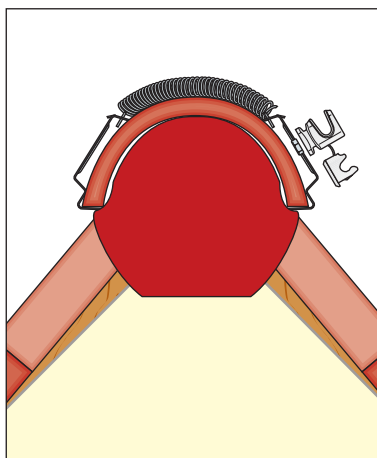


Fig. 5.4.3.2 SPANNsnap with plastic DEHNSnap conductor holder

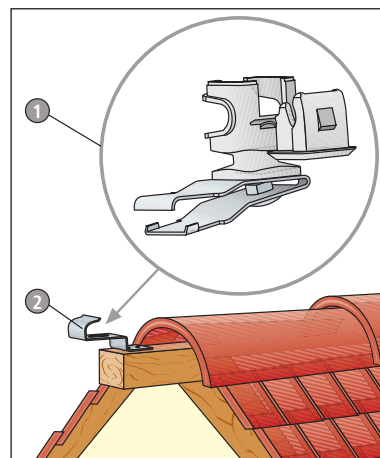


Fig. 5.4.3.3 FIRSTsnap for mounting on existing ridge clamp

180 – 280 mm with laterally adjustable conductor leading for Rd 8 mm conductors.

- ⇒ FIRSTsnap conductor holder with DEHNSnap synthetic conductor holder for putting on existing ridge clamps for dry ridges.

For dry ridges, the DEHNSnap conductor holder (1) (Figure 5.4.3.3) is put on the ridge clamp already on the structure (2) and tightened manually (only turn DEHNSnap).

Grooved pantiles:

UNIsnap roof conductor holder with preformed struts is used for the roof surfaces. The conductor holder is bent by hand before being hooked into the battens. Additionally, it can also be secured with nails (Figure 5.4.3.4).

Smooth tiles (Figure 5.4.3.5)

Slate roofs:

When using it on slate roofs, the internal hook system is bent (Figure 5.4.3.6) or equipped with a supplementary clamp (Part No. 204 089).

Grooved tiles:

- ⇒ FLEXIsnap roof conductor holder for grooved tiles, for direct fitting on the groove (Figure 5.4.3.7).

The flexible stainless steel strut is pushed between the grooved tiles.

By pressing on the top grooved tile, the stainless steel strut is deformed and adapts itself to the shape of the groove.

Thus it is fixed tightly under the tile. This application with an aluminium strut makes it easy to adapt to the shape of the groove.

A notch is provided for an eventually existing window hook. The strut of the holder can also be nailed down (holes in the strut).

- ⇒ Roof conductor holders with preformed strut, for hooking into the bottom groove for pantile roofs (Figure 5.4.3.8).

Flat tiles or slabs:

DEHNSnap conductor holder (1) (Figure 5.4.3.9) and its clamping device (2) is pushed in between the flat tiles (3) (e.g. plain tile) or slabs and tightened manually (only turn DEHNSnap).

Overlapped constructions:

In case of overlapped constructions (3) (e.g. slabs and natural slates), DEHNSnap conductor holder (1) (Figure 5.4.3.10) with clamping terminals (2) is pushed on from the side and secured with a screw driver when the holder is open.

For slabs laid on a slat, DEHNSnap can also be turned to allow a plumb conductor leading.

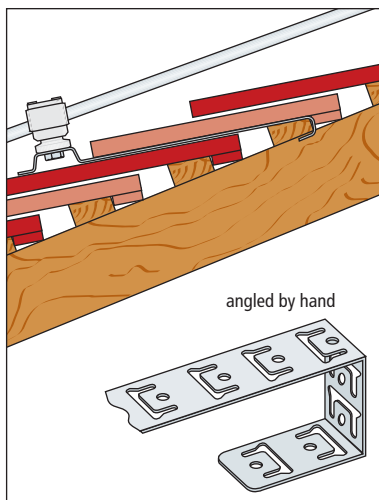


Fig. 5.4.3.4 UNIsnap roof conductor holder with preformed strut – Used on grooved pantiles

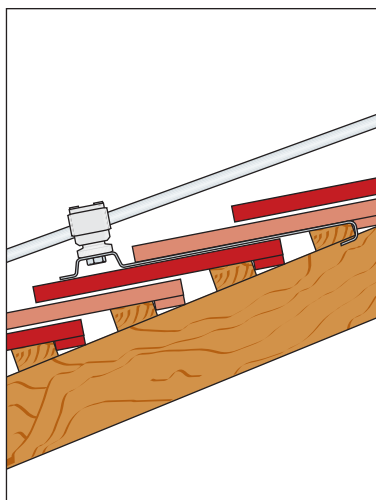


Fig. 5.4.3.5 UNIsnap roof conductor holder with preformed strut – Used on smooth tiles, e.g. plain tiles

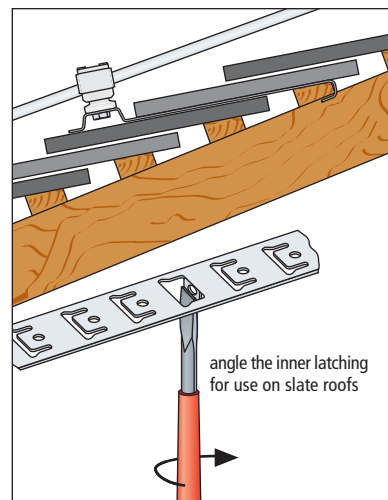


Fig. 5.4.3.6 UNIsnap roof conductor holder with preformed strut – Used on slate roofs

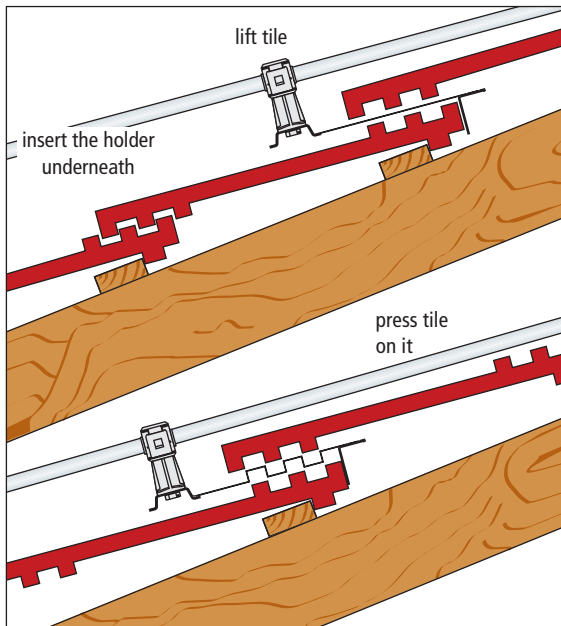


Fig. 5.4.3.7 Conductor holder for direct fitting on the seams

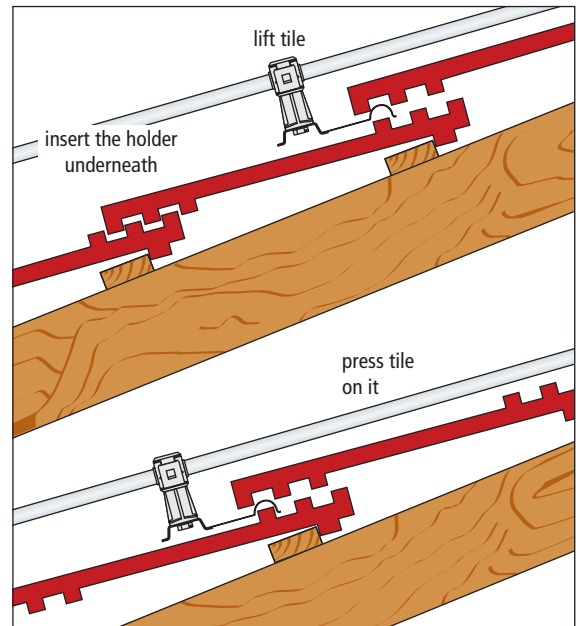


Fig. 5.4.3.8 Roof conductor holder for hanging into the bottom seam of pantile roofs

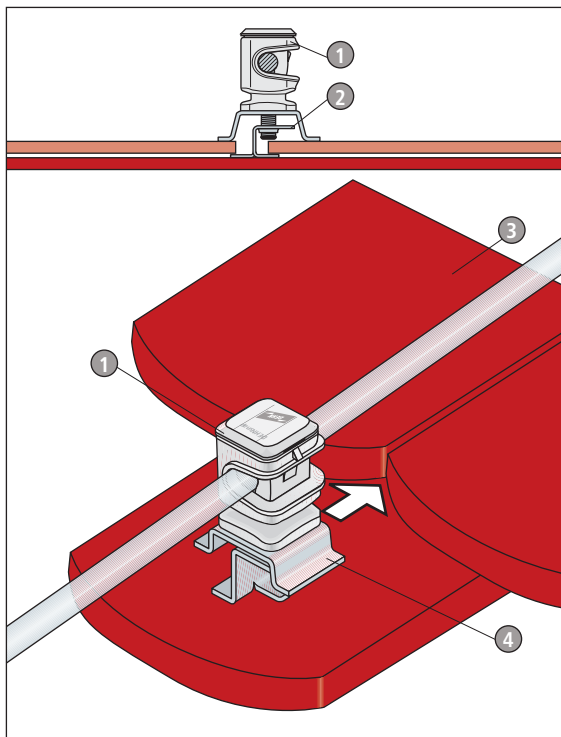


Fig. 5.4.3.9 ZIEGELsnap, for fixing between flat tiles or plates

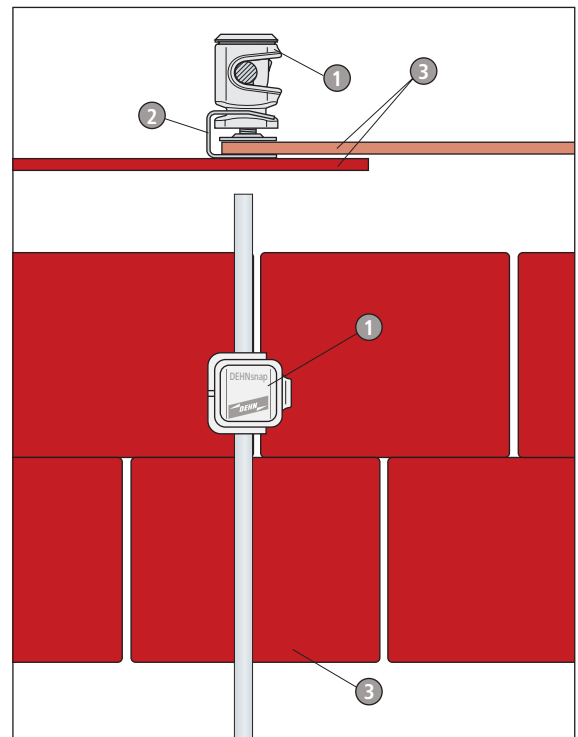


Fig. 5.4.3.10 PLATTENsnap roof conductor holder for overlapped construction

5.5 Earth-termination systems

A detailed explanation of the terms used in earth-termination technology is contained in IEC 62305-3 (EN 62305-3) "Lightning protection – physical damage to structures and life hazard", HD 637 S1 "Power installations exceeding 1 kV", IEC 60050-826 "International electrotechnical vocabulary Part 826: Electrical installations" and IEC 60364-5-54 "Electrical installations of buildings – Part 5-54". In Germany DIN 18014 is additionally applicable for foundation of earth electrodes. Below, we repeat only the terminology which is required to understand the following designs.

Terminology

Earth

is the conductive ground whose electrical potential at each point is set equal to zero as agreed. The word "earth" also the designation for both the earth as a place as well as earth as a material, e.g.

the type of soil: humus, loam, sand, gravel and rock.

Reference earth

(neutral earth) is the part of the earth, especially the surface of the earth outside the sphere of influence of an earth electrode or an earth-termination system, in which, between two arbitrary points, no perceptible voltages arising from the earthing current occur (Figure 5.5.1).

Earth electrode

is a conductive component or several conductive components in electrical contact with the earth and forming an electrical connection with it (includes also foundation earth electrodes).

Earth-termination system

is a localised entirety of interconnected conductive earth electrodes or metal components acting as such, (e.g. reinforcements of concrete foundations, cable metal sheaths in contact with the earth, etc.).

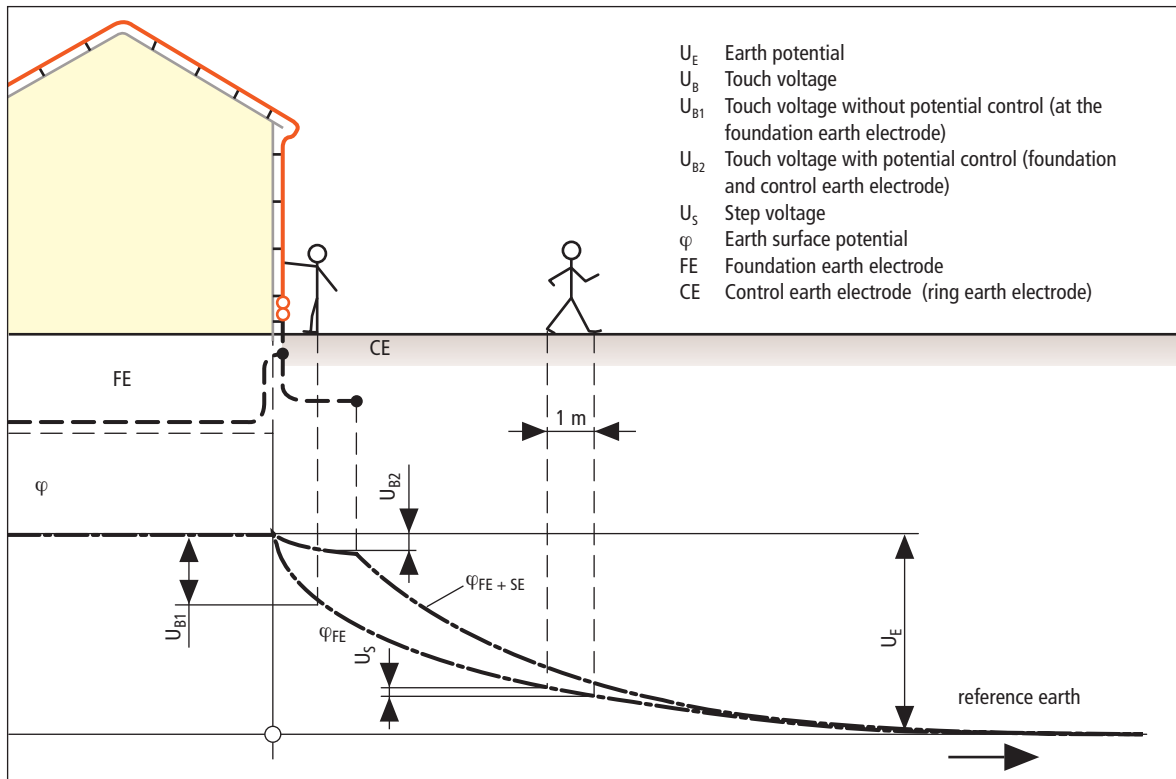


Fig. 5.5.1 Earth surface potential and voltages at a foundation earth electrode FE and control earth electrode CE flown through by currents

Earthing conductor

is a conductor connecting a system component to be earthed to an earth electrode and which is installed above the ground or insulated in the ground.

Lightning protection earthing

is the earthing installation of a lightning protection system to discharge lightning currents into the earth.

Below some types of earth electrodes and their classification are described according to location, form and profile.

Classification according to location

Surface earth electrode

is an earth electrode generally driven in at a shallow depth down to 1 m. It can consist of round material or flat strips and be designed as a star-type, ring or meshed earth electrode or a combination thereof.

Earth rod

is an earth rod generally driven in plumb down to greater depths. It can consist of round material or material with another profile, for example.

Foundation earth electrode

comprises one or more conductors embedded in concrete which is in contact with the earth over a wide area.

Control earth electrode

is an earth electrode whose form and arrangement serves more to control the potential than to maintain a certain earth electrode resistance.

Ring earth electrode

is an earth electrode underneath or on the surface of the earth, leading as closed ring around the structure.

Natural earth electrode

is a metal component in contact with the earth or with water either directly or via concrete, whose original function is not as an earth electrode but which acts as an earth electrode (reinforcements of concrete foundations, conduits, etc.).

Classification according to form and profile

One distinguishes between:

flat strip earth electrodes, cruciform earth electrodes and earth rods.

Types of resistance

Specific earth resistance

ρ_E is the specific electrical resistance of the earth. It is given in Ωm and represents the resistance between two opposite sides of a cube of earth with edges of 1 m in length.

Earth electrode resistance

R_A of an earth electrode is the resistance of the earth between the earth electrode and reference earth. R_A is practically a resistance.

Impulse earth resistance

R_{st} is the resistance as lightning currents traverse from one point of an earth-termination system to the reference earth.

Voltages at current carrying earth-termination systems, control of potential

Earth potential

U_E is the voltage arising between an earth-termination system and reference earth (Figure 5.5.1).

Potential of the earth's surface

φ is the voltage between one point of the earth's surface and reference earth (Figure 5.5.1).

Touch voltage

U_B is the part of the potential of the earth's surface which can be bridged by humans (Figure 5.5.1), the current path via the human body running from hand to foot (horizontal distance from touchable part around 1 m) or from one hand to the other.

Step voltage

U_S is the part of the potential of the earth's surface which can be bridged by humans taking one step 1 m long, the current path via the human body running from one foot to the other (Figure 5.5.1).

Potential control

is the effect of the earth electrodes on the earth potential, particularly the potential of the earth's surface (Figure 5.5.1).

Equipotential bonding

for lightning protection system is the connection of metal installations and electrical systems to the lightning protection system via conductors, lightning current arresters or isolating spark gaps.

Earth electrode resistance / Specific earth resistance

Earth electrode resistance R_A

The conduction of the lightning current via the earth electrode into the ground does not happen at one point but rather energises a particular area around the earth electrode.

The type of earth electrode and the way it is installed must now be chosen to ensure that the voltages affecting the surface of the earth (touch and step voltages) do not assume hazardous values.

The earth electrode resistance R_A of an earth electrode can best be explained with the help of a metal sphere buried in the ground.

If the sphere is buried deep enough, the current discharges radially to be equally distributed over the surface of the sphere. **Figure 5.5.2a** illustrates this case; as a comparison, **Figure 5.5.2b** illustrates the case of a sphere buried just under the earth's surface.

The concentric circles around the surface of the sphere represent surface of equal voltage. The earth electrode resistance R_A is composed of the partial resistances of individual layers of the sphere connected in series. The resistance of such a layer of the sphere is calculated using

$$R = \rho_E \cdot \frac{l}{q}$$

where ρ_E is the specific earth resistance of the ground, assuming it is homogeneous,

l the thickness of an imaginary layer of the sphere

and

q the medial surface of this layer of the sphere.

To illustrate this, we assume a metal sphere 20 cm in diameter buried at a depth of 3 m at a specific earth resistance of 200 Ωm .

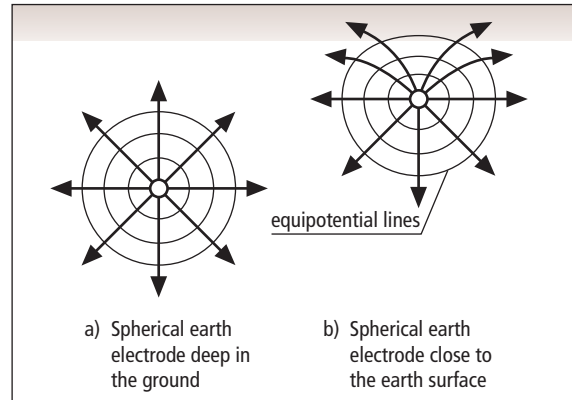


Fig. 5.5.2 Current distribution from the spherical earth electrode

If now the increase in earth electrode resistance for the different layers of the sphere is calculated, then as a function of the distance from the centre of the sphere, a curve as shown in **Figure 5.5.3** is obtained.

The earth electrode resistance R_A for the spherical electrode is calculated using:

$$R_A = \frac{\rho_E \cdot 100}{2\pi \cdot r_K} \cdot \frac{1 + \frac{r_K}{2t}}{2}$$

ρ_E Specific earth resistance in Ωm

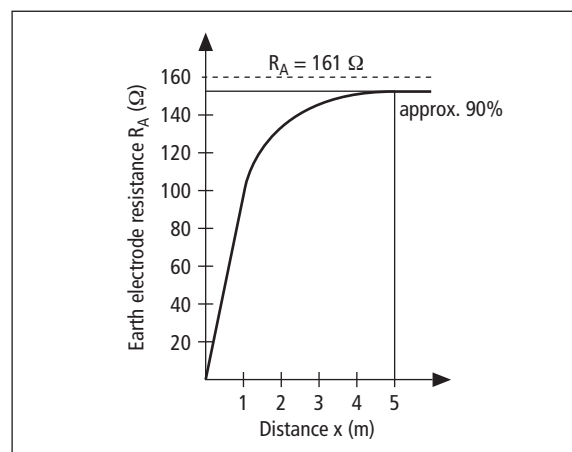


Fig. 5.5.3 Earth electrode resistance R_A of a spherical earth electrode with \varnothing 20 cm, 3 m deep, at $\rho_E = 200 \Omega\text{m}$ as a function of the distance x from the centre of the sphere

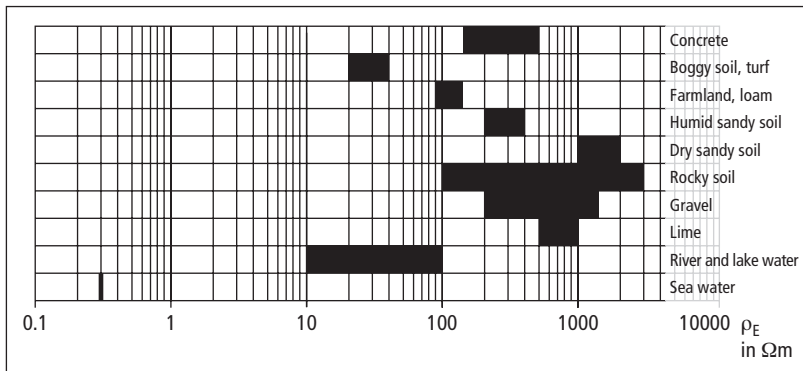


Fig. 5.5.4 Specific earth resistance ρ_E of different ground types

t Burial depth in cm

r_K Radius of the spherical earth electrode in cm

This formula gives a earth electrode resistance of $R_A = 161 \Omega$ for the spherical earth electrode.

The trace of the curve in **Figure 5.5.3** shows that the largest fraction of the total earth electrode resistance occurs in the immediate vicinity of the earth electrode. Thus, for example, at a distance of 5 m from the centre of the sphere, 90 % of the total earth electrode resistance R_A has already been achieved.

Specific earth resistance ρ_E

The specific earth resistance ρ_E which determines the magnitude of the earth electrode resistance R_A of an earth electrode, is a function of the composi-

tion of the soil, the amount of moisture in the soil and the temperature. It can fluctuate between wide limits.

Values for various types of soil

Figure 5.5.4 gives the fluctuation ranges of the specific earth resistance ρ_E for various types of soil.

Seasonal fluctuations

Extensive measurements (literature) have shown that the specific earth resistance varies greatly according to the burial depth of the earth electrode. Owing to the negative temperature coefficient of the ground ($\alpha = 0.02 \dots 0.004$), the specific earth resistance attain a maximum in winter and a minimum in summer. It is therefore advisable to convert the measured values obtained from earth electrodes to the maximum prospective values, since even under unfavourable conditions (very low temperatures), permissible values must not be exceeded. The curve of the specific earth resistance ρ_E as a function of the season (ground temperature) can be represented to a very good approximation by a sinus curve having its maximum around the middle of February and its minimum around the middle of August. Investigations have further shown that, for earth electrodes buried not deeper than around 1.5 m, the maximum deviation of the specific earth resistance from the average is around $\pm 30 \%$ (**Figure 5.5.5**).

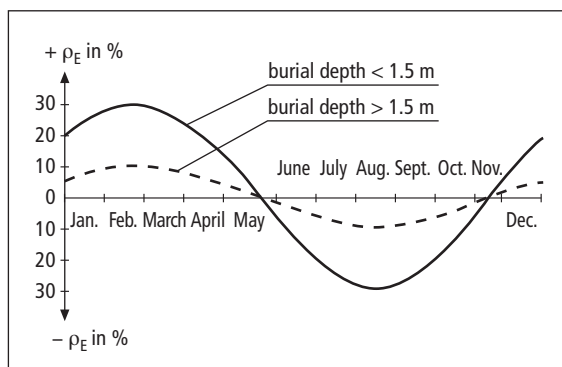


Fig. 5.5.5 Specific earth resistance ρ_E as a function of the seasons without influencing of rainfall (burial depth of the earth electrode < 1.5 m)

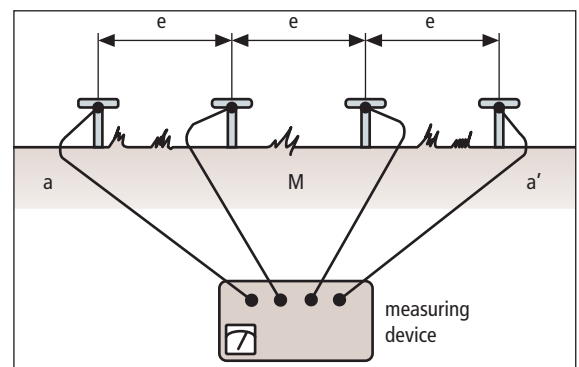


Fig. 5.5.6 Determination of the specific earth resistance ρ_E with a four-terminal measuring bridge acc. to the WENNER method

For earth electrodes buried deeper (particularly for earth rods), the fluctuation is merely $\pm 10\%$. From the sineshaped curve of the specific earth resistance in **Figure 5.5.5**, the earthing electrode resistance R_A of an earth-termination system measured on a particular day can be converted to the maximum prospective value.

Measurement

The specific earth resistance ρ_E is determined using an earthing measuring bridge with 4 clamps which operates according to the null method.

Figure 5.5.6 illustrates the measuring arrangement of this measuring method named after WENNER. The measurement is carried out from a fixed central point M which is retained for all subsequent measurements. Four measuring probes (earthing

spikes 30 ... 50 cm long) are driven into the soil along a line a – a' pegged out in the ground. From the measured resistance R one can determine the specific earth resistance ρ_E of the ground:

$$\rho_E = 2\pi \cdot e \cdot R$$

R measured resistance in Ω

e probe distance in m

ρ_E average specific earth resistance in Ωm down to a depth corresponding to the probe distance e

By increasing the probe distance e and re-tuning the earthing measuring bridge, the curve of the

Earth electrode	Rough estimate	Auxiliary
Surface earth electrode (star-type earth electrode)	$R_A = \frac{2 \cdot \rho_E}{l}$	–
Earth rod	$R_A = \frac{\rho_E}{l}$	–
Ring earth electrode	$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$	$d = 1.13 \cdot \sqrt[3]{A}$
Meshed earth electrode	$R_A = \frac{\rho_E}{2 \cdot d}$	$d = 1.13 \cdot \sqrt[3]{A}$
Earth plate	$R_A = \frac{\rho_E}{4.5 \cdot a}$	–
Hemispherical earth electrode	$R_A = \frac{\rho_E}{\pi \cdot d}$	$d = 1.57 \cdot \sqrt[3]{V}$
<p>R_A Earth electrode resistance (Ω) ρ_E Specific earth resistance (Ωm) l Length of earth electrode (m) d Diameter of a ring earth electrode, of the area of the equivalent circuit or of a hemispherical earth electrode (m) A Area (m^2) of the enclosed area of a ring or meshed earth electrode a Edge length (m) of a square earth plate, for rectangular plates value: $\sqrt{b \cdot c}$, while b and c are the two sides of the rectangle V Content (m^3) of a single foundation element</p>		

Table 5.5.1 Formulae for calculating the earth electrode resistance R_A for different earth electrodes

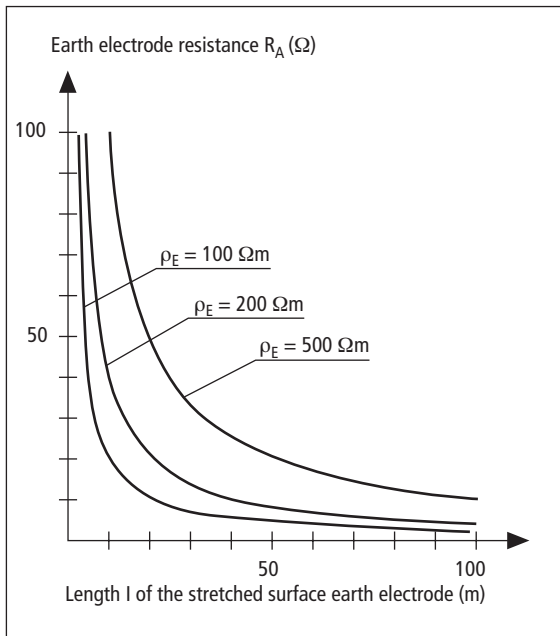


Fig. 5.5.7 Earth electrode resistance R_A as a function of length l of the surface earth electrode at different specific earth resistance ρ_E

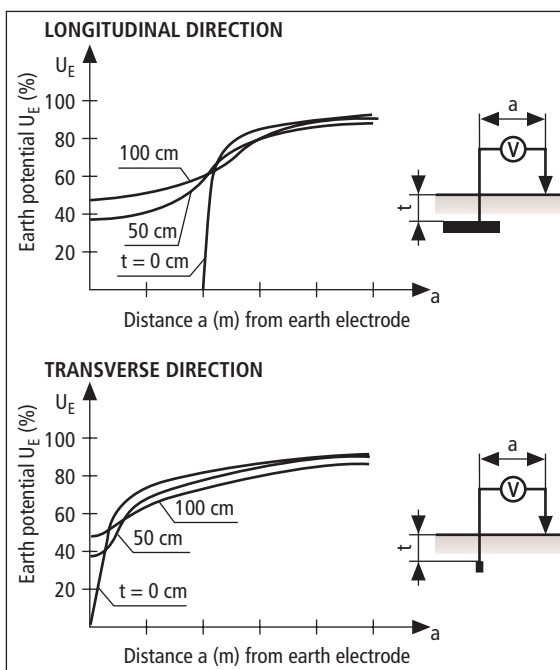


Fig. 5.5.8 Earth potential U_E between supply conductor and earth surface as a function of the distance from the earth electrode, at an earth strip (8 m long) in different depths

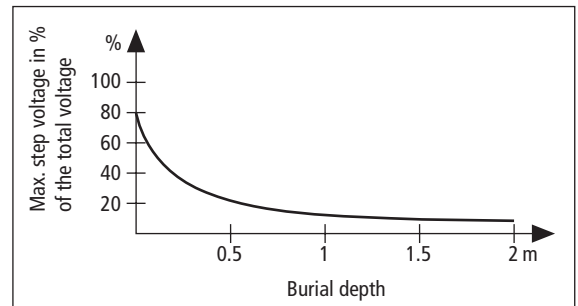


Fig. 5.5.9 Max. step voltage U_s as a function of the burial depth for a stretched earth strip

specific earth resistance can be determined ρ_E as a function of the depth.

Calculation of earth electrode resistances

Table 5.5.1 gives the formulae for calculating the earth electrode resistances of the most common types of earth electrode. In practice, these approximate formulae are quite sufficient. The precise formulae for the calculations must be taken from the following sections.

Straight surface earth electrode

Surface earth electrodes are generally embedded horizontally in the ground at a depth of 0.5 ... 1 m. Since the layer of soil covering the earth electrode dries out in summer and freezes in winter, the earth electrode resistance R_A of such a surface earth electrode is calculated as if it lays on the surface of the ground:

$$R_A = \frac{\rho_E}{\pi \cdot l} \cdot \ln \frac{l}{r}$$

R_A Earth electrode resistance of a stretched surface earth electrode in Ω

ρ_E Specific earth resistance in Ωm

l Length of the surface earth electrode in m

r Quarter width of steel strip in m or diameter of the round wire in m

The earth electrode resistance R_A as a function of the length of the earth electrode can be taken from **Figure 5.5.7**.

Figure 5.5.8 shows the transverse and longitudinal earthing potential U_E for an 8 m long flat strip earth electrode.

The effect of the burial depth on the earthing potential can be clearly seen.

Figure 5.5.9 illustrates the step voltage U_s as a function of the burial depth.

In practice, the calculation is done using the approximate formula in **Table 5.5.1**:

$$R_A = \frac{2 \cdot \rho_E}{l}$$

Earth rod

The earth electrode resistance R_A of a earth rod is calculated using:

$$R_A = \frac{\rho_E}{2\pi \cdot l} \cdot \ln \frac{l}{r}$$

- R_A earth electrode resistance in Ω
- ρ_E Specific earth resistance in Ωm
- l Length of the earth rod in m
- r Radius of the earth rod in m

As an approximation, the earth electrode resistance R_A can be calculated using the approximate formula given in **Table 5.5.1**:

$$R_A = \frac{\rho_E}{l}$$

Figure 5.5.10 shows the earth electrode resistance R_A as a function of the rod length l and the specific earth resistance ρ_E .

Combination of earth electrodes

If the soil conditions require several earth rods, the driving down depth of the earth rods is applicable for the corresponding minimum distance of the different earth rods which have to be interconnected.

The earth electrode resistance calculated using the formulae and the measurement results given in the diagrams apply to low frequency d.c. current

and a.c. current provided that the expansion of the earth electrode is relatively small (a few hundred metres). For longer lengths, e.g. for surface earth electrodes, the a.c. current also has an inductive part.

Furthermore, the calculated earth electrode resistances do not apply to lightning currents. This is where the inductive part plays a role, which can lead to higher values of the impulse earthing resistance for larger expansion of the earth-termination system.

Increasing the length of the surface earth electrodes or earth rods above 30 m reduces the impulse earth electrode resistance by only an insignificant amount. It is therefore expedient to combine several shorter earth electrodes. In such cases, because of their interaction, care must be taken that the actual total earth electrode resistance is greater than the value calculated from the individual resistances connected in parallel.

Star-type earth electrodes

Star-type earth electrodes in the form of cruciform surface earth electrodes are important when relatively low earth electrode resistances shall be created in poorly conducting ground at an affordable price.

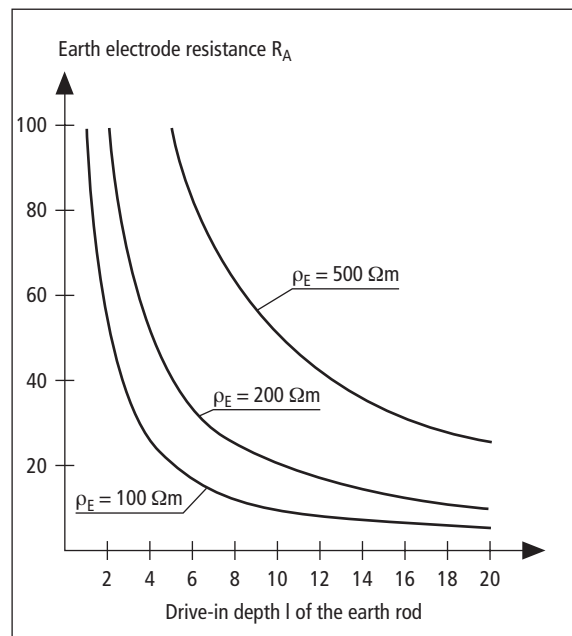


Fig. 5.5.10 Earth electrode resistance R_A of earth rods as a function of their length l at different specific earth resistances ρ_E

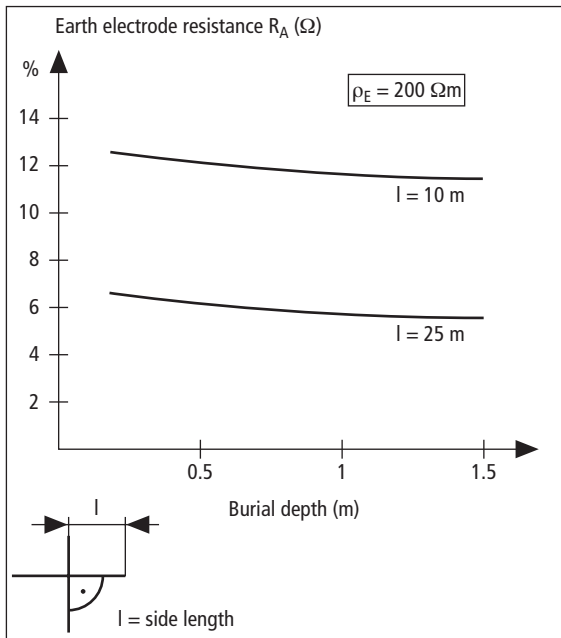


Fig. 5.5.11 Earth electrode resistance R_A of crossed surface earth electrode (90 °) as a function of the burial depth

The earth electrode resistance R_A of a cruciform surface earth electrode whose sides are at 90 ° to each other is calculated using:

$$R_A = \frac{\rho_E}{4\pi \cdot l} \cdot \ln \frac{l}{r} + 1.75$$

R_A Earth electrode resistance of the cruciform surface earth electrode in Ω

ρ_E Specific earth resistance in Ωm

l Side length in m

d Half a bandwidth in m or diameter of the round wire in m

As a rough approximation, for longer lengths of the star arrangement ($l > 10$ m), the earth electrode resistance R_A can be determined using the total length of the star obtained from the equations in **Table 5.5.1**.

Figure 5.5.11 shows the curve of the earth electrode resistance R_A of cruciform surface earth electrodes as a function of the burial depth;

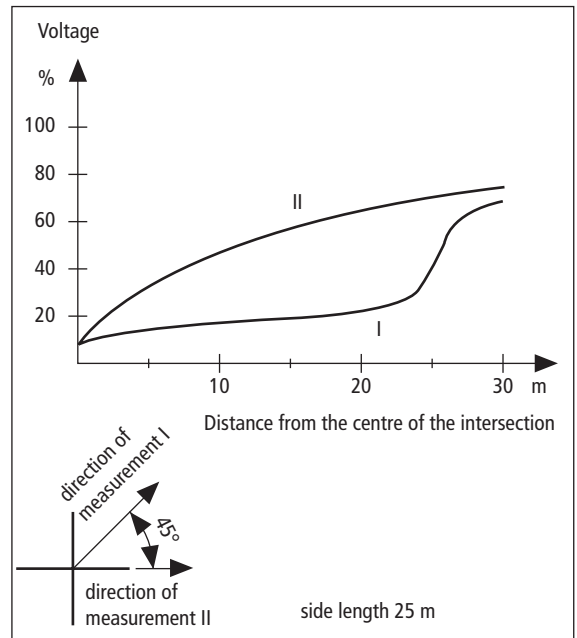


Fig. 5.5.12 Earth potential U_E between the supply conductor of the earth electrode and earth surface of crossed surface earth electrode (90 °) as a function of the distance from the cross centre point (burial depth 0.5 m)

Figure 5.5.12 shows the curve of the earthing voltage.

For star-type earth electrodes, the angle between the individual arms should be greater than 60 °. According to **Figure 5.5.12** the earth electrode resistance of a meshed earth electrode is given by the formula:

$$R_A = \frac{\rho_E}{2 \cdot d}$$

Where d is the diameter of the analogous circle having the same area as the meshed earth electrode, which is determined as follows:

For rectangular or polygonal dimensions of the meshed earth electrode:

$$d = \sqrt{\frac{4 \cdot A}{\pi}}$$

A Area of the meshed earth electrode

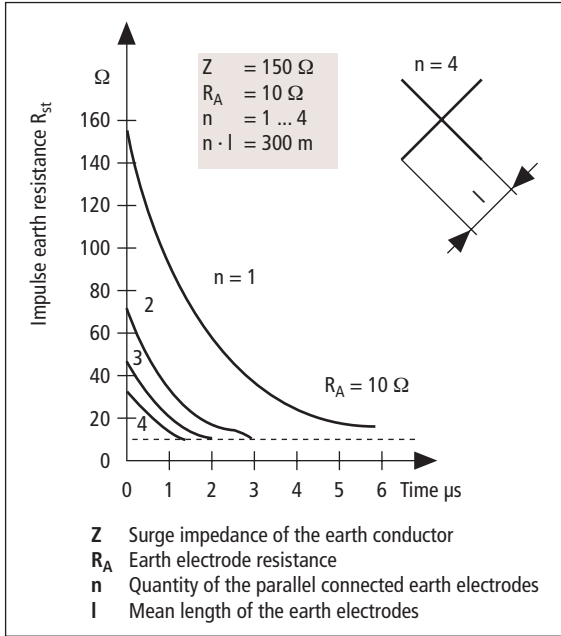


Fig. 5.5.13 Impulse earth resistance R_{st} of single or multiple star-type earth electrodes with equal length

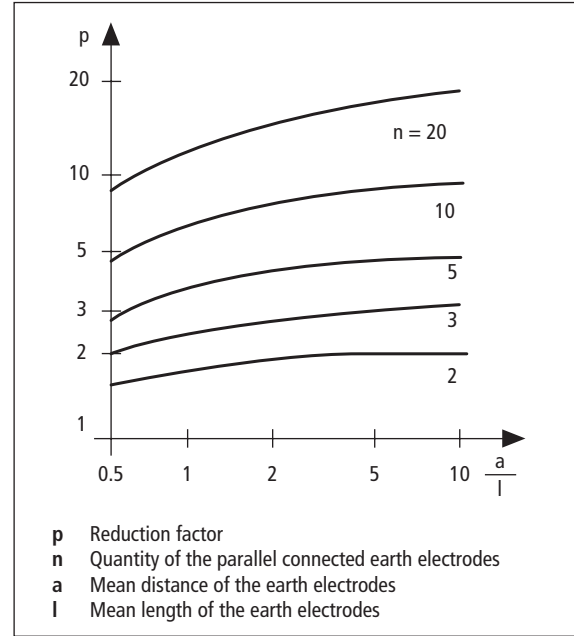


Fig. 5.5.14 Reduction factor p for calculating the total earth electrode resistance R_A of earth rods connected in parallel

For square dimensions (edge length b):

$$d = 1.1 \cdot b$$

Figure 5.5.13 illustrates the curve of the impulse earth electrode resistance of surface earth electrodes with single and multiple star for square-wave voltages.

As can be seen from this diagram, for a given length, it is more expedient to install a radial earth electrode than one single arm.

Foundation earth electrode

The earth electrode resistance of a metal conductor in a concrete foundation can be calculated as an approximation using the formula for hemispherical earth electrodes:

$$R_A = \frac{\rho_E}{\pi \cdot d}$$

Where d is the diameter of the analogous hemisphere having the same volume as the foundation:

$$d = 1.57 \cdot \sqrt[3]{V}$$

V Volume of the foundation

When calculating the earth electrode resistance, one must be aware that the foundation earth electrode can only be effective if the concrete body has a large contact area with the surrounding ground. Water repellent, isolating shielding significantly increases the earth electrode resistance, or isolate the foundation earth electrode (see 5.5.2).

Earth rods connected in parallel

To keep the interactions within acceptable limits, the distances between the individual earth electrodes and earth rods connected in parallel should not be less than the pile depth, if possible.

If the individual earth electrodes are arranged roughly in a circle and if they all have about the same length, then the earth electrode resistance can be calculated as follows:

$$R_A = \frac{R_{A'}}{p}$$

Where $R_{A'}$ is the average earth electrode resistance of the individual earth electrodes. The reduction factor p as a function of the length of the earth electrode, the distance of the individual earth electrodes and the number of earth electrodes can be taken from **Figure 5.5.14**.

Combination of flat strip earth electrodes and earth rods

If sufficient earth electrode resistance is provided by earth rods, for example from deep water carrying layers in sandy soil, then the earth rod shall be as close as possible to the object to be protected. If a long feed is required, it is expedient to install a radial multiple star-type earth electrode in parallel to this in order to reduce the resistance as the current rises.

As an approximation, the earth electrode resistance of a flat strip earth electrode with earth rod can be calculated as if the flat strip earth electrode were extended by the drive-in depth of the earth rod.

$$R_A \approx \frac{\rho_E}{l_{flat\ strip} + l_{earth\ rod}}$$

Ring earth electrode

For circular ring earth electrodes with large diameters ($d > 30$ m), the earth electrode resistance is calculated as an approximation using the formula for the flat strip earth electrode (where the circumference $\pi \cdot d$ is used for the length of the earth electrode):

$$R_A = \frac{\rho_E}{\pi^2 \cdot d} \cdot \ln \frac{\pi \cdot d}{r}$$

r Radius or the round conductor or quarter width of the flat strip earth electrode in m

For non-circular ring earth electrodes, the earth electrode resistance is calculated by using the diameter d of an analogous circle with the same area:

$$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$$

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$

A Area enclosed by the ring earth electrode

Implementation

According to the standards, each installation to be protected must have its own earth-termination system which must be fully functional in itself without requiring metal water pipes or earthed conductors of the electrical installation.

The magnitude of the earth electrode resistance R_A is of only secondary importance for protecting a structure or installation against physical damage. It is important that the equipotential bonding at ground level is carried out systematically and the lightning current is safely distributed in the ground.

The lightning current i raises the structure to be protected to the earthing potential U_E

$$U_E = i \cdot R_A + \frac{1}{2} \cdot L \cdot \frac{di}{dt}$$

with respect to the reference earth.

The potential of the earth's surface decreases with increasing distance from the earth electrode (**Figure 5.5.1**).

The inductive voltage drop across the earth electrode during the lightning current rise must only be taken into account for extended earth-termination systems (e.g. as required for long surface earth electrodes in poorly conducting soils with bedrock). In general, the earth electrode resistance is determined only by the ohmic part.

If isolated conductors are led into the structure, the earthing potential U_E has its full value with respect to the conductor.

In order to avoid the risk of punctures and flashovers here, such conductors are connected via isolating spark gaps or with live conductors via surge protective devices (see DEHN main catalogue for Surge Protection) to the earth-termination sys-

tem as part of the lightning equipotential bonding.

In order to keep touch and step voltages as low as possible, the magnitude of the earth electrode resistance must be limited.

The earth-termination system can be designed as a foundation earth electrode, a ring earth electrode and, for structures with large surface areas, as a meshed earth electrode and, in special cases, also as an individual earth electrode.

In Germany foundation earth electrodes must be designed in accordance with DIN 18014.

The foundation earth electrode must be designed as a closed ring and arranged in the foundations of the external walls of the structure, or in the foundation slab, in accordance with DIN 18014. For larger structures, the foundation earth electrode should contain interconnections to prevent an exceeding of the max. mesh size 20 m x 20 m.

The foundation earth electrode must be arranged to be enclosed by concrete on all sides. For steel strips in non-reinforced concrete, the earth electrode must be installed on edge.

In the service entrance room, a connection must be established between foundation earth electrode and equipotential bonding bar. According to IEC 62305-3 (EN 62305-3), a foundation earth electrode must be equipped with terminal lugs for connection of the down-conductor systems of the external lightning protection system to the earth-termination system.

Due to the risk of corrosion at the point where a terminal lug comes out of the concrete, supplementary corrosion protection should be considered (with PVC sheath or by using stainless steel with Material No. 1.4571).

The reinforcement of plate and strip foundations can be used as a foundation earth electrode if the required terminal lugs are connected to the reinforcement and the reinforcements are interconnected via the joints.

Surface earth electrodes must be installed in a depth of at least 0.5 m.

The impulse earthing resistance of earth electrodes is a function of the maximum value of the lightning current and of the specific earth resistance. See also **Figure 5.5.13**. The effective length of the earth electrode for the lightning current is calculated as an approximation as follows:

Surface earth electrode:

$$l_{eff} = 0.28 \sqrt{\hat{i} \cdot \rho_E}$$

Earth rod:

$$l_{eff} = 0.2 \sqrt{\hat{i} \cdot \rho_E}$$

l_{eff} Effective length of the earth electrode in m

\hat{i} Peak value of the lightning current in kA

ρ_E Specific earth resistance Ωm

The impulse earth resistance R_{st} can be calculated using the formulae in **(Table 5.5.1)**, where the effective length of the earth electrode l_{eff} is used for the length l .

Surface earth electrodes are always advantageous when the upper soil layers have less specific resistance than the subsoil.

If the ground is relatively homogeneous (i.e. if the specific earth resistance at the surface is roughly the same as it is deep down) then, for a given earth electrode resistance, the construction costs of surface earth electrodes and earth rods are roughly the same.

According to **Figure 5.5.15**, an earth rod must have only around half the length of a surface earth electrode.

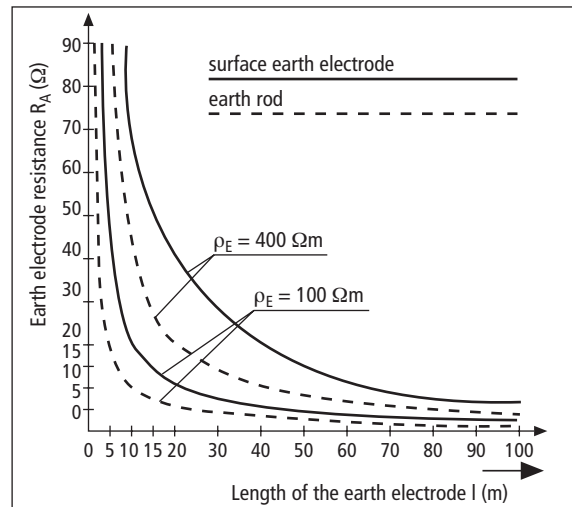


Fig. 5.5.15 Earth electrode resistance R_A of surface and earth rods as a function of the length of the earth electrode l

If the conductivity of the ground is better deep down than it is on the surface, e.g. because of ground water, then an earth rod is generally more cost-effective than the surface earth electrode. The issue of whether earth rods or surface earth electrodes are more cost-effective in a particular case, can often only be decided by measuring the specific earth resistance as a function of the depth. Since earth rods are easy to assemble and achieve excellent constant earth electrode resistances without the need to dig a trench and without damaging the ground, these earth electrodes are also suitable for improving existing earth-termination system.

5.5.1 Earth-termination systems in accordance with IEC 62305-3 (EN 62305-3)

Earth-termination systems are the continuation of air-termination and down-conductor systems to discharge the lightning current into the earth. Further functions of the earth-termination system are to create equipotential bonding between the down conductors and a potential control in the vicinity of the walls of the structure.

It must be borne in mind that a common earth-termination system for the various electrical systems (lightning protection, low voltage systems and telecommunications systems) is preferable. This earth-termination system must be connected to the equipotential bonding (MEBB – main equipotential bonding bar).

Since IEC 62305-3 (EN 62305-3) assumes a systematic lightning equipotential bonding, no particular value is required for the earth electrode resistance.

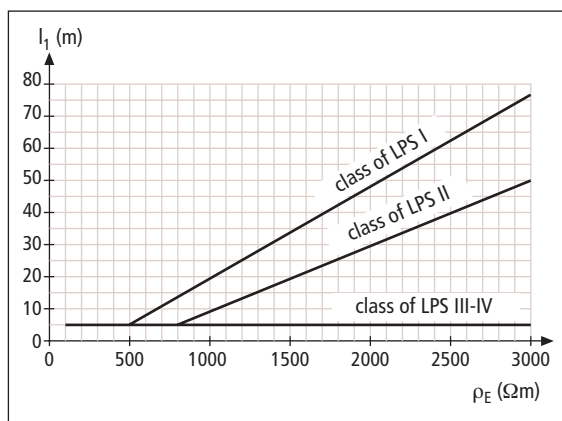


Fig. 5.5.1.1 Minimum lengths of earth electrodes

Generally, however, a low earth resistance (less than 10 Ω, measured with low frequency) is recommended.

The standard classifies earth electrode arrangements into **Type A** and **Type B**.

For both Type A and B earth electrode arrangements, the minimum earth electrode length l_1 of the earthing conductor is a function of the class of lightning protection system (**Figure 5.5.1.1**)

The exact specific earth resistance can only be determined by on-site measurements using the "WENNER method" (four-conductor measurement).

Earth electrode Type A

Earth electrode arrangement Type A describes individually arranged horizontal star-type earth electrodes (surface earth electrodes) or vertical earth electrodes (earth rods), each of which must be connected to a down-conductor system.

There must be at least 2 earth electrodes Type A. Lightning protection systems Class III and IV require a minimum length of 5 m for earth electrodes. For lightning protection systems, Class I and II the length of the earth electrode is determined as a function of the specific ground resistance. The minimum length for earth electrodes l_1 can be taken from **Figure 5.5.1.1**.

Minimum length of each earth electrode is:

$$l_1 \times 0.5 \quad \text{for vertical or slanted earth electrodes}$$

$$l_1 \quad \text{for star-type earth electrodes}$$

The values determined apply to each individual earth electrode.

For combinations of the various earth electrodes (vertical and horizontal) the equivalent total length should be taken into account.

The minimum length for the earth electrode can be disregarded if an earth electrode resistance of less than 10 Ω is achieved.

Earth rods are generally driven vertically down to greater depths into natural soil which is generally initially encountered below the foundations. Earth electrode lengths of 9 m have provided the advantage of lying at greater depths in soil layers whose specific resistance is generally lower than in the areas closer to the surface.

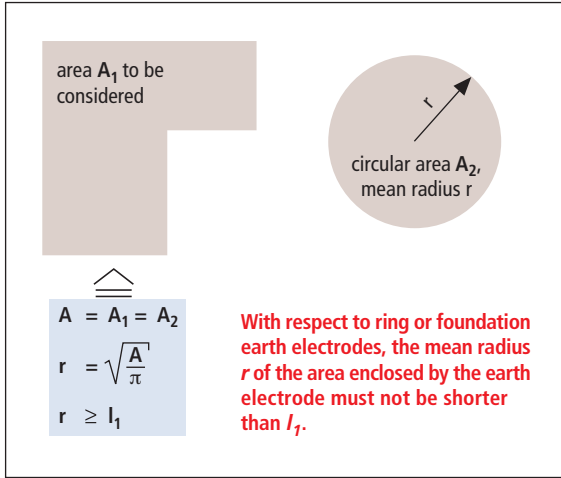


Fig. 5.5.1.2 Earth electrode Type B – Determination of the mean radius – example calculation

In frosty conditions, it is recommended to consider the first 100 cm of a vertical earth electrode as ineffective.

Earth electrodes Type A do not fulfill the equipotential bonding requirements between the down conductors and the potential control.

Earth electrodes Type A must be interconnected to split the current equally. This is important for calculating the separation distance s . Earth electrodes Type A can be interconnected underground or on surface. When upgrading existing installations the interconnection of the individual earth electrodes can also be realised by laying a conductor in the building or structure.

Earth electrode Type B

Earth electrodes of the Type B arrangement are ring earth electrodes around the structure to be protected, or foundation earth electrodes. In Germany the requirements on these earth electrodes are described in DIN 18014.

If it is not possible to have a closed ring outside around the structure, the ring must be completed using conductors inside the structure. Conduits or other metal components which are permanently electrically conductive can also be used for this purpose. At least 80 % of the length of the earth electrode must be in contact with the earth to ensure that, when calculating the separation distance, the earth electrode Type B can be used as the base.

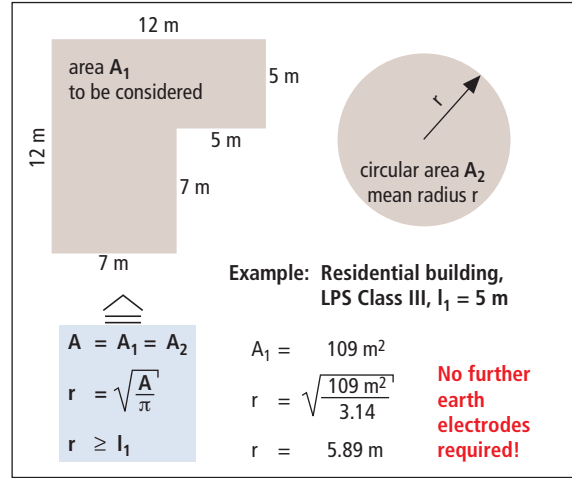


Fig. 5.5.1.3 Earth electrode Type B – Determination of the mean radius

The minimum lengths of the earth electrodes corresponding to the Type B arrangement are a function of the class of lightning protection system. For lightning protection systems Class I and II, the minimum length for earth electrodes is also determined as a function of the specific ground resistance (see also **Figure 5.5.4**).

For earth electrodes Type B, the average radius r of the area enclosed by the earth electrode must be not less than the given minimum length l_1 .

To determine the average radius r , the area under consideration is transferred into an equivalent circular area and the radius is determined as shown in **Figures 5.5.1.2** and **5.5.1.3**.

Below a calculation example:

If the required value of l_1 is greater than the value r corresponding to the structure, supplementary star-type earth electrodes or vertical earth electrodes (or slanted earth electrodes) must be added, their respective lengths l_r (radial/horizontal) and l_v (vertical) being given by the following equations:

$$l_r = l_1 - r$$

$$l_v = \frac{l_1 - r}{2}$$

The number of supplementary earth electrodes must not be less than the number of down conductors, but a minimum of 2. These supplementary earth electrodes shall be connected to the ring earth electrode so as to be equidistant around the circumference.

If supplementary earth electrodes have to be connected to the foundation earth electrode, care must be taken with the materials of the earth electrode and the connection to the foundation earth electrode. It is preferable to use stainless steel with Material No. 1.4571 (**Figure 5.5.2.1**).

The following systems can make additional demands on the earth-termination system, for example:

- ⇒ Electrical systems – conditions of disconnection from supply with respect to the type of network (TN-, TT-, IT systems) in accordance with IEC 60364-4-41: 2005, mod and HD 60364-4-41: 2007
- ⇒ Equipotential bonding in accordance with IEC 60364-5-54: 2002 and HD 60364-5-54: 2007
- ⇒ Electronic systems – data information technology
- ⇒ Antenna earthing installation in accordance with VDE 0855 (German standard)
- ⇒ Electromagnetic compatibility
- ⇒ Substation in or near the structure in accordance with HD 637 S1 and En 50341-1

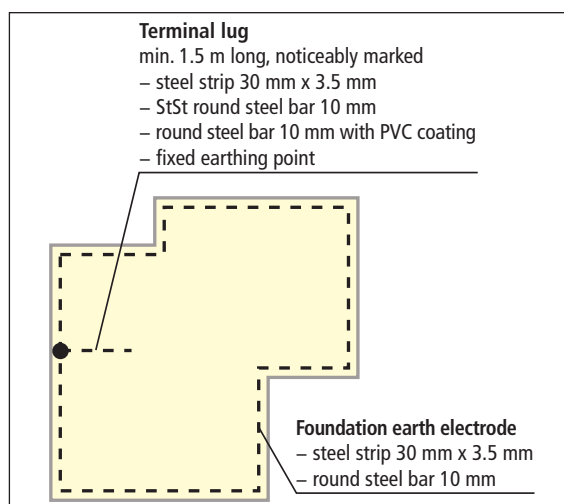


Fig. 5.5.2.1 Foundation earth electrode with terminal lug

5.5.2 Earth-termination systems, foundation earth electrodes and foundation earth electrodes for special structural measures

Foundation earth electrodes – Earth electrodes Type B

DIN 18014 (German standard) specifies the requirements on foundation earth electrodes.

Many national and international standards specify foundation earth electrodes as a preferred earth electrode because, when professionally installed, it is enclosed in concrete on all sides and hence corrosion-resistant. The hygroscopic characteristics of concrete generally produce a sufficiently low earth electrode resistance.

The foundation earth electrode must be installed as a closed ring in the strip foundation or the bed-plate (**Figure 5.5.2.1**) and thus also acts primarily as the equipotential bonding. The division into meshes $\leq 20 \text{ m} \times 20 \text{ m}$ and the terminal lugs to the outside required to connect the down conductors of the external lightning protection system, and to the inside for equipotential bonding, must be considered (**Figure 5.5.2.2**).

According to DIN 18014, the installation of the foundation earth electrode is an electrical engineering measure to be carried out or monitored by a recognised **specialist electrical engineer**.

The question of how to install the foundation earth electrode must be decided according to the measure required to ensure that the foundation

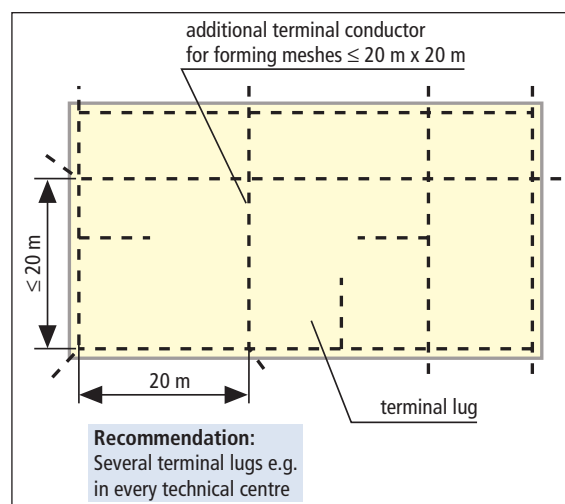


Fig. 5.5.2.2 Mesh of a foundation earth electrode



Fig. 5.5.2.3 Foundation earth electrode

earth electrode is enclosed on all sides as the concrete is being poured in.

Installation in non-reinforced concrete

Non-reinforced foundations, e.g. strip foundations of residential structures (**Figure 5.5.2.3**), require the use of spacers.

Only by using the spacers at distances of approx. 2 m, is it possible to ensure that the foundation earth electrode is “lifted up” and can be enclosed on all sides by concrete.

Installation in reinforced concrete

When using steel mats, reinforcement cages or reinforcement irons in foundations, it is not only possible to connect the foundation earth electrode to these natural iron components, but this should be done. The function of the foundation earth electrode is thus made even more favourable. There is no need to use spacers. The modern methods of laying concrete and then vibrating it, ensure that the concrete also “flows” under the foundation earth electrode enclosing it on all sides.

Figure 5.5.2.4 illustrates one possible application for the horizontal installation of a flat strip as a foundation earth electrode. The intersections of the foundation earth electrode must be connected so as to be capable of carrying currents. Galvanised steel is sufficient as material of the foundation earth electrode.

Terminal lugs to the outside into the ground must have supplementary corrosion protection at the outlet point. Suitable materials are, for example, plastic sheathed steel wire (owing to the risk of fracture of the plastic sheath at low temperatures, special care must be taken during the installation),



Fig. 5.5.2.4 Foundation earth electrode in use

high-alloy stainless steel, Material No. 1.4571, or fixed earthing terminals.

If professionally installed, the earth electrode is enclosed on all sides by concrete and hence corrosion-resistant.

When designing the foundation earth electrode, meshes no bigger than 20 m x 20 m shall be realised. This mesh size bears no relation to the class of lightning protection system of the external lightning protection system.

Modern building techniques employ various types of foundations in a wide variety of designs and sealing versions.

The terminal insulation regulations have also influenced the design of the strip foundations and foundation slabs. For foundation earth electrodes installed in new structures in accordance with DIN 18014, the insulation affects their installation and arrangement.

Perimeter insulation / Base insulation

“Perimeter” is the earth-touching area of the wall and base of a structure. The perimeter insulation is the external heat insulation around the structure. The perimeter insulation seated on the external sealing layer encloses the structure so that there is no heat bridge and protects the sealing additionally against mechanical damage.

The magnitude of the specific resistance of the perimeter insulating plates is a decisive factor when considering the effect of perimeter insulation on the earth electrode resistance of foundation earth electrodes in conventional arrangements in the foundation (strip foundation, foundation slab). Thus, for a polyurethane rigid foam

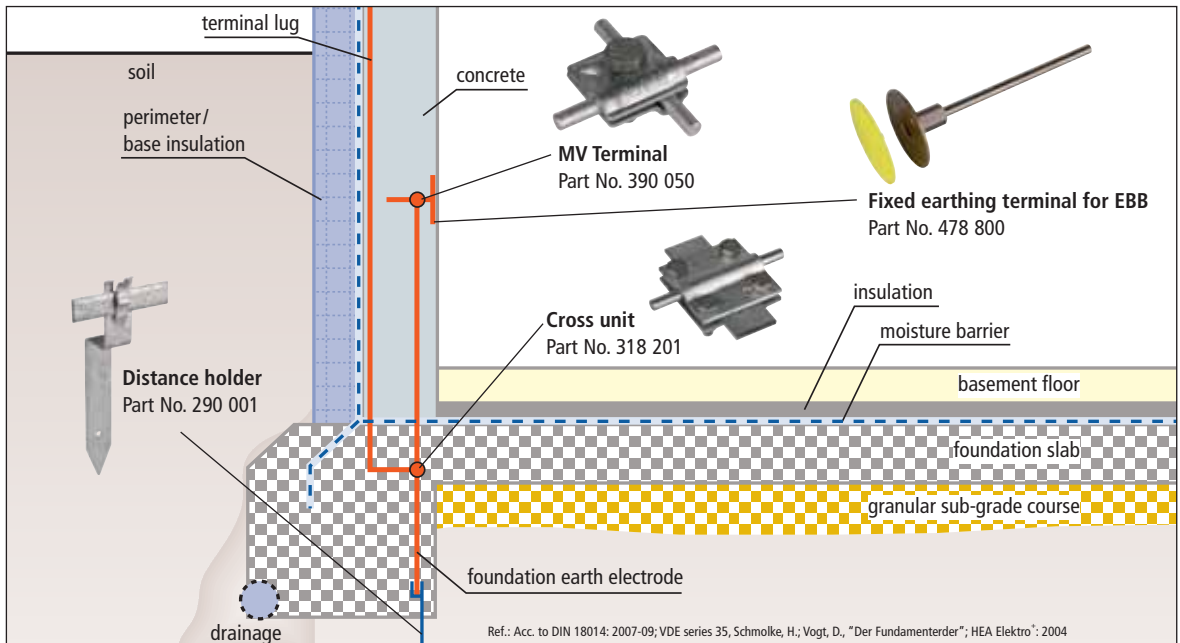


Fig. 5.5.2.5 Arrangement of a foundation earth electrode in a strip foundation (insulated basement wall)

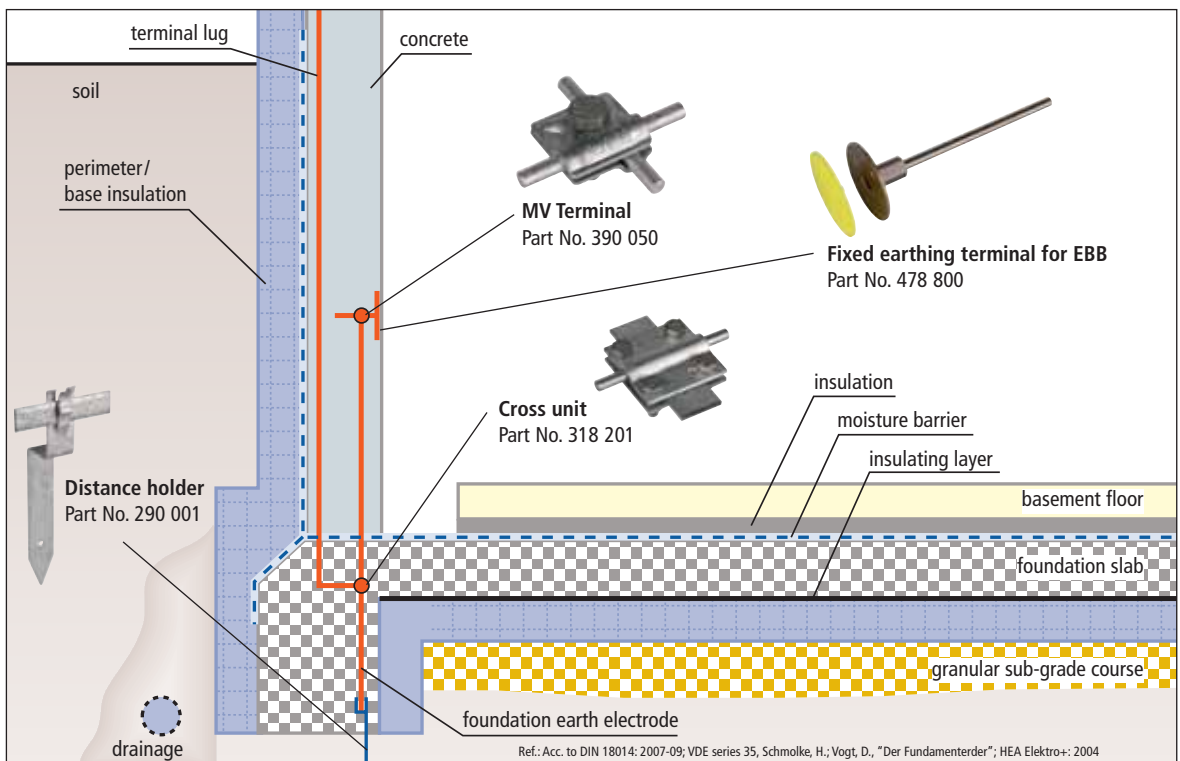


Fig. 5.5.2.6 Arrangement of a foundation earth electrode in a strip foundation (insulated basement wall and foundation slab)

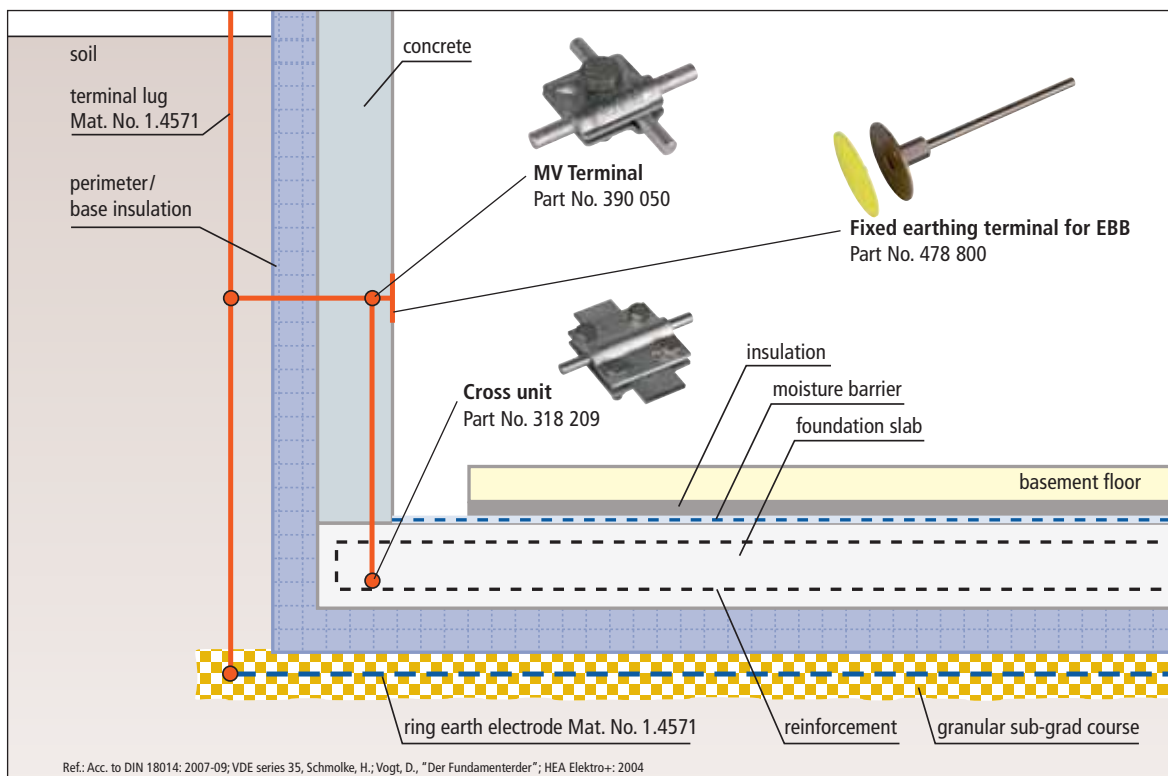


Fig. 5.5.2.7 Arrangement of a foundation earth electrode in case of a closed floor slab (fully insulated)

with bulk density 30 kg/m^2 , for example, a specific resistance of $5.4 \cdot 10^{12} \Omega \text{m}$ is given. In contrast, the specific resistance of concrete lies between $150 \Omega \text{m}$ and $500 \Omega \text{m}$. This alone shows that, in the case of continuous perimeter insulation, a conventional foundation earth electrode arranged in the foundations has practically no effect. The perimeter insulation also acts as an electrical insulator. The diagrams below illustrate the various ways of insulating the foundations and walls for structures with perimeter and base insulation.

Figures 5.5.2.5 to 5.5.2.7 show the arrangement of the foundation earth electrodes at structures with perimeter and base insulation.

The arrangement of the earth electrode in the strip foundation with insulated sides towards the outside and the bedplate is not regarded as critical (**Figure 5.5.2.5 and 5.5.2.6**).

If the foundation slab is completely insulated, the earth electrode must be installed below the bedplate. Material V4A (Material No. 1.4571) should be used (**Figure 5.5.2.7**).

It is efficient to install fixed earthing terminals, especially for reinforced structures. In such cases, care must be taken that the installation during the construction phase is carried out professionally (**Figure 5.5.2.8**).



Fig. 5.5.2.8 Fixed earthing terminal

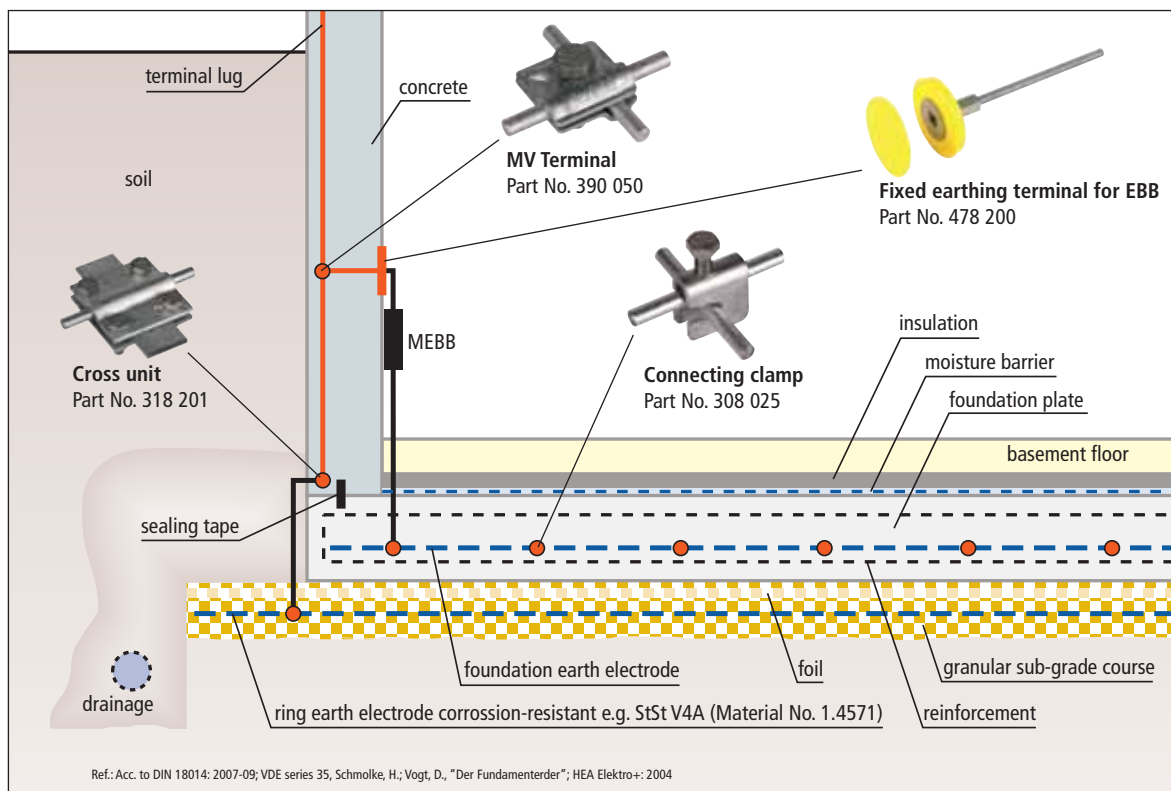


Fig. 5.5.2.9 Arrangement of the foundation earth electrode in case of a closed tank "white tank"

Black tank, white tank

In structures erected in regions with a high groundwater level, or in locations, e.g. on hillsides, with "pressing" water, the cellars are equipped with special measures to prevent moisture penetrating. The outer walls surrounded by earth, and the foundation slab are sealed against the penetration of water to ensure that no troublesome moisture can form on the inside of the wall.

Modern building techniques apply both above mentioned processes for sealing against penetrating water.

One particular issue in this context is whether the efficiency of a foundation earth electrode is still provided for maintaining the measures to protect against life hazards in accordance with IEC 60364-4-41, and as a lightning protection earth electrode in accordance with IEC 62305-3 (EN 62305-3).

Foundation earth electrodes for structures with white tank

The name "white tank" is used to express the opposite of "black tank": a "white tank" receives no additional treatment on the side facing the earth, hence it is "white".

The "white tank" is manufactured from a special type of concrete. Due to the aggregates used at manufacturing of the concrete the concrete body is absolutely waterproof. In contrast to former years there is no risk of humidity penetrating a few centimeters into the tank. Therefore an earth electrode is laid outside of structures with white tank.

Figure 5.5.2.8 shows the designing of an earth connection by a fixed earthing terminal.

Figure 5.5.2.9 illustrates the arrangement of the foundation earth electrode in a white tank.

Earth electrodes for structures with black tank

The name "black tank" derives from the multi-layered strip of black bitumen applied to the sections of the structure which are outside in the ground. The body of the structure is coated with bitumen/tar which is then covered by generally up to 3 layers of bitumen strips.

A ring conductor set into the foundation slab above the seal can act as the potential control in the structure. Due to the high-impedance insulation to the outside, however, the earth electrode is ineffective.

In order to comply with the earthing requirements stipulated in the various standards, an earth electrode, e.g. a ring earth electrode, must be installed externally around the structure or below all seals in the granular sub-grade course.

Wherever possible, the external earth electrode should be led into the structure above the seal of the structure (**Figure 5.5.2.10**), in order to ensure the tightness of the tank also in the long term. A waterproof penetration of the "black tank" is only

possible using a special bushing for the earth electrodes.

Fibre concrete foundation slabs

Fibre concrete is a type of concrete which forms a heavy-duty concrete slab with steel fibres added to the liquid concrete before hardening.

The steel fibres are approx. 6 cm long and have a diameter of 1 – 2 mm. The steel fibres are slightly wavy and are admixed equally to the liquid concrete. The proportion of steel fibres is around 20 – 30 kg/m³ concrete.

The admixture gives the concrete slab both a high compression strength and also a high tensile strength and, compared to a conventional concrete slab with reinforcement, it also provides a considerably higher elasticity.

The liquid concrete is poured on site. This allows to create large areas with a smooth surface and no joints. It is used for bedplates in the foundations of large halls, for example.

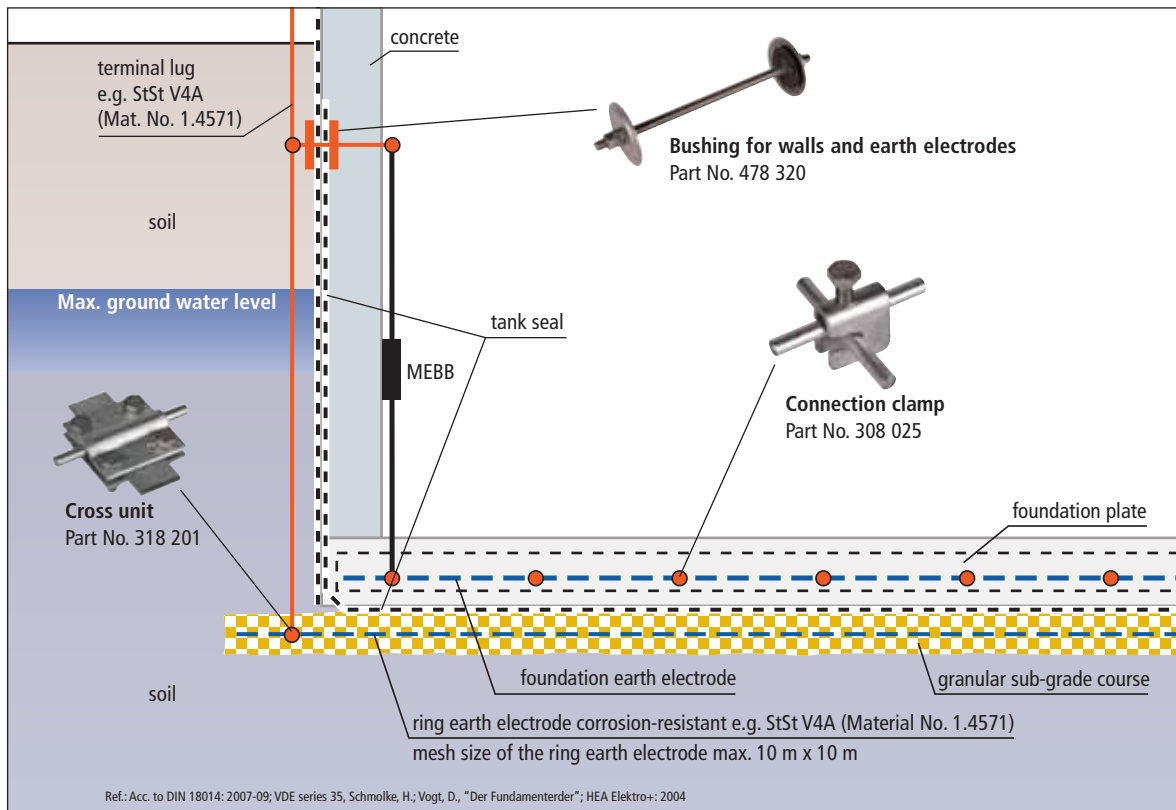


Fig. 5.5.2.10 Arrangement of the earth electrode in case of a closed tank "black tank"

Fibre concrete has no reinforcement. This requires a supplementary ring conductor or a meshed network to be constructed for installing earthing measures. The earthing conductor can be set in the concrete and, if it is made of galvanised material, it must be enclosed on all sides. This is very difficult to do on site.

It is therefore recommended to install a corrosion-resistant high-alloy stainless steel, Material No. 1.4571, below the subsequent concrete bedplate. The corresponding terminal lugs have to be considered.

Note:

A specialist must install the earthing conductors and connecting components in concrete. If this is not possible, the building contractor can undertake the work only if it is supervised by a specialist.

5.5.3 Ring earth electrode – Earth electrode Type B

In Germany the national standard DIN 18014 stipulates that all new structures must have foundation earth electrodes. The earth-termination system of existing structures can be designed in the form of a ring earth electrode (**Figure 5.5.3.1**).

This earth electrode must be installed in a closed ring around the structure or, if this is not possible, a connection to close the ring must be made inside the structure.

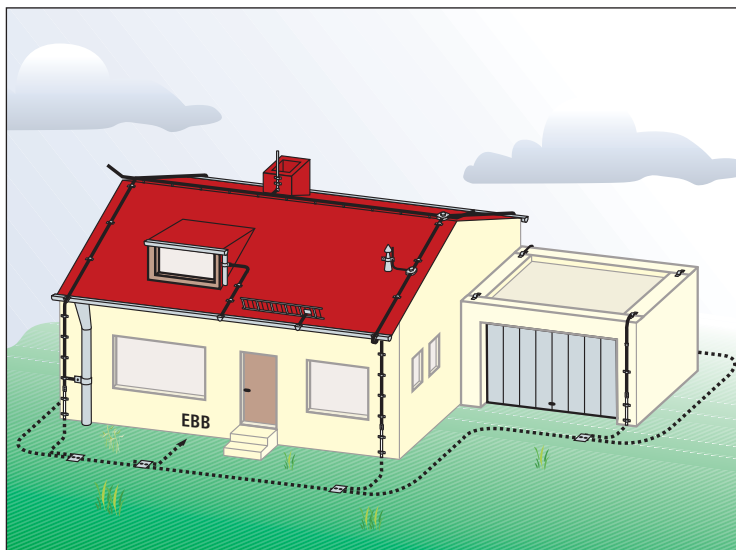


Fig. 5.5.3.1 Ring earth electrode around a residential building

80 % of the conductors of the earth electrode shall be installed so as to be in contact with the earth. If this 80 % cannot be achieved, it has to be checked if supplementary earth electrodes Type A are required.

The requirements on the minimum length of earth electrodes according to the class of lightning protection system must be taken into account (see Chapter 5.5.1).

When installing the ring earth electrode, care must be taken that it is installed at a depth > 0.5 m and a distance of 1 m from the structure.

If the earth electrode is driven in as previously described, it reduces the step voltage and thus acts as a potential control around the structure.

This earth electrode should be installed in natural soil. Setting it in gravel or ground filled with construction waste worsens the earth electrode resistance.

When choosing the material of the earth electrode with regard to corrosion, the local conditions must be taken into consideration. It is advantageous to use stainless steel. This earth electrode material does not corrode nor does it subsequently require the earth-termination system to be refurbished with time-consuming and expensive measures such as removal of paving, tar coatings or even steps, for installing a new flat strip.

In addition, the terminal lugs must be particularly protected against corrosion.

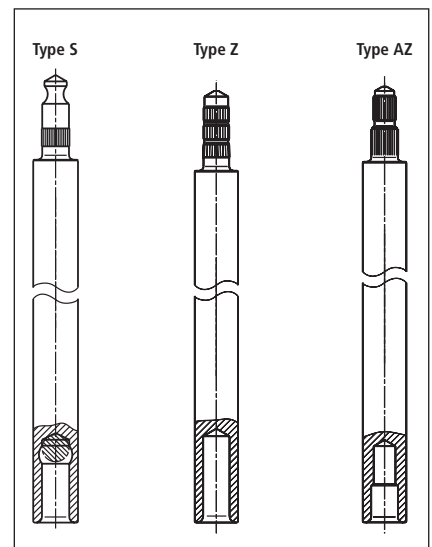


Fig. 5.5.4.1 Couplings of DEHN earth rods

5.5.4 Earth rod – Earth electrode Type A

The sectional earth rods, System DEHN, are manufactured from special steel and hot-dip galvanised, or they consist of high-alloy stainless steel with Material No. 1.4571 (the high-alloy stainless steel earth electrode is used in areas especially at risk from corrosion). The particular feature of these earth rods is their coupling point, which allows the earth rods to be connected without increasing their diameter.

Each rod has a bore at its lower end, while the other end of the rod has a corresponding spigot (Figure 5.5.4.1).

With DEHN earth electrode Type “S”, the soft metal insert deforms as it is driven into the bore, creating an excellent electrical and mechanical connection.

With DEHN earth electrode Type “Z”, the high coupling quality is achieved with a multiply knurled spigot.

With DEHN earth electrode Type “AZ”, the high coupling quality is achieved with a multiply knurled and shouldered spigot.



Fig. 5.5.4.2 Driving the earth rod in with a work scaffolding and a vibrating hammer

The advantages of the DEHN earth rods are:

- ⇒ Special coupling:
- ⇒ no increase in diameter so that the earth rod is in close contact with the ground along the whole of its length
- ⇒ Self-closing when driving in the rods
- ⇒ Simple to drive in with vibration hammers (Figure 5.5.4.2) or mallets
- ⇒ Constant resistance values are achieved since the earth rods penetrate through the soil layers which are unaffected by seasonal changes in moisture and temperature
- ⇒ High corrosion resistance as a result of hot-dip galvanising (zinc coating 70 µm thick)
- ⇒ Galvanised earth rods also provide hot-galvanised coupling points
- ⇒ Easy to store and transport since individual rods are 1.5 or 1 m long.

5.5.5 Earth electrodes in rocky ground

In bedrock or stony ground, surface earth electrodes such as ring earth electrodes or star-type earth electrodes are often the only way of creating an earth-termination system.

When installing the earth electrodes, the flat strip or round material is laid on the stony ground or on the rock. The earth electrode should be covered with gravel, wet-mix slag aggregate or similar.

It is advantageous to use stainless steel Material No. 1.4571 as earth electrode material. The clamped points should be installed with particular care and be protected against corrosion (anticorrosive band).

5.5.6 Intermeshing of earth-termination systems

An earth-termination system can serve a wide variety of purposes.

The purpose of protective earthing is to safely connect electrical installations and equipment to earth potential and to prevent life hazard and physical damage to property in the event of an electrical fault.

The lightning protection earthing system takes over the current from the down conductors and discharges it into the ground.

The functional earthing installation serves to ensure that the electrical and electronic installations operate safely and trouble-free.

The earth-termination system of a structure must be used for all earthing tasks together, i.e. the earth-termination system deals with all earthing tasks. If this were not the case, potential differences could arise between the installations earthed on different earth-termination systems.

Previously, a “clean earth” was sometimes applied in practice for functional earthing of the electronic equipment, separately from the lightning protection and the protective earth. This is extremely disadvantageous and can even be dangerous. In the event of lightning effects, great potential differences up to a few 100 kV occur in the earth-termination system. This can lead to destruction of electronic installations and also to life hazards. Therefore, IEC 62305-3 and -4 (EN 62305-3 and -4) require continuous equipotential bonding within a structure.

The earthing of the electronic systems can be constructed to have a radial, central or intermeshed 2-dimensional design within a structure, (**Figure 5.5.6.1**). This depends both on the electromagnetic environment and also on the characteristics of the electronic installation. If a larger structure

comprises more than one building, and if these are connected by electrical and electronic conductors, then combining the individual earthing systems can reduce the (total) earth resistance. In addition, the potential differences between the structures are also reduced considerably. This diminishes noticeably the voltage load of the electrical and electronic connecting cables. The interconnection of the individual earth-termination systems of the structure should produce a meshed network. The meshed earthing network should be constructed to contact the earth-termination systems at the point where the vertical down conductors are also connected. The smaller the mesh size of the network of the earthing installation, the smaller the potential differences between the structures in the event of a lightning strike. This depends on the total area of the structure. Mesh sizes from 20 m x 20 m up to 40 m x 40 m have proved to be cost-effective. If, for example, high vent stacks (preferred points of strike) are existing, then the connections around this part of the plant should be made closer, and, if possible, radial with circular interconnections (potential control) When choosing the material for the conductors of the meshed earthing network, the corrosion and material compatibility must be taken into account.

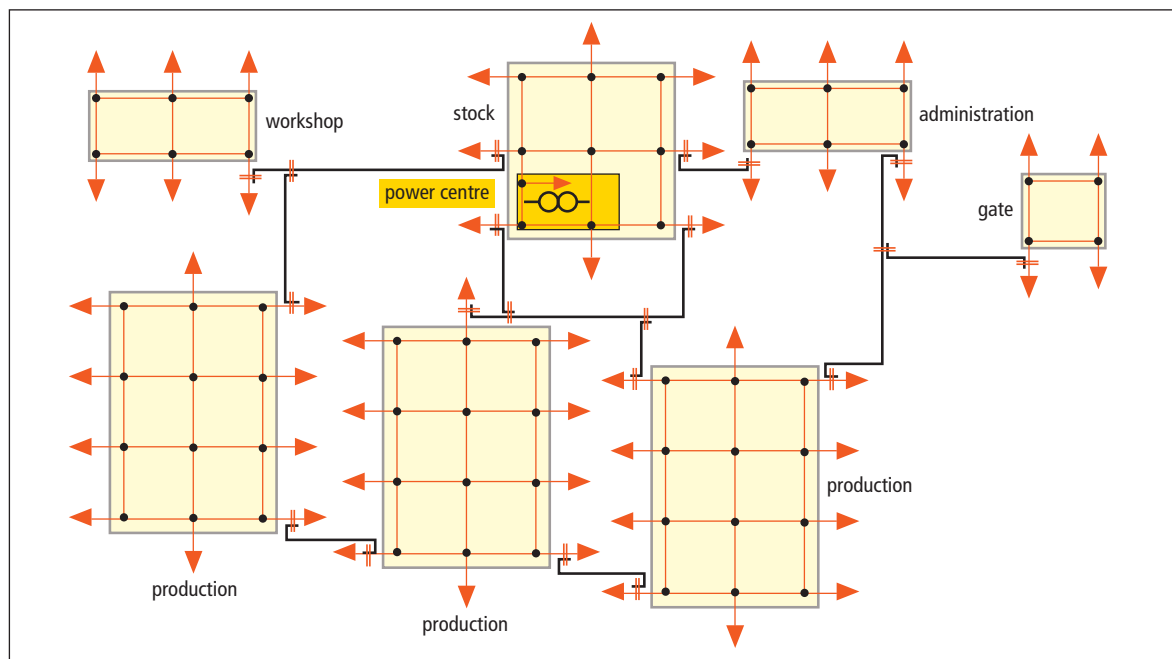


Fig. 5.5.6.1 Intermeshed earth-termination system of an industrial facility

5.5.7 Corrosion of earth electrodes

5.5.7.1 Earth-termination systems with particular consideration of corrosion

Metals in immediate contact with soil or water (electrolytes) can be corroded by stray currents, corrosive soils and the formation of voltaic cells. It is not possible to protect earth electrodes from corrosion by completely enclosing them, i.e. by separating the metals from the soil, since all the usual sheaths employed until now have had a high electrical resistance and therefore negate the effect of the earth electrodes.

Earth electrodes made of a uniform material can be threatened by corrosion from corrosive soils and the formation of concentration cells. The risk of corrosion depends on the material and the type and composition of the soil.

Corrosion damage due to the formation of voltaic cells is being increasingly observed. This cell formation between different metals with widely different metal/electrolyte potentials has been known for many years. What is not widely realised, however, is that the reinforcements of concrete foundations can also become the cathode of a cell and hence cause corrosion to other installations.

With the changes to the way buildings are constructed – larger reinforced concrete structures and smaller free metal areas in the ground – anode/cathode surface ratio is becoming more and more unfavourable, and the risk of corrosion of the more base metals is inevitably increasing.

An electrical isolation of installations acting as anodes to prevent this cell formation is only possible in exceptional cases. The aim nowadays is to integrate all earth electrodes including those metal installations connected to the earth in order to achieve equipotential bonding and hence maximum safety against touch voltages at faults or lightning strikes.

In high voltage installations, high voltage protective earth electrodes are increasingly connected to low voltage operating earth electrodes in accordance with HD 637 S1. Furthermore IEC 60364-4-41, mod and HD 60364-4-41 requires the integration of conduits and other installations into the shock hazard protective measures. Thus, the only way of preventing or at least reducing the risk of corrosion for earth electrodes and other installations in contact with them is choosing suitable materials for the earth electrodes.

In Germany, the national standard DIN VDE 0151 “Material and minimum dimensions of earth electrodes with respect to corrosion” has been available since June 1986 as a white paper. Apart from decades of experience in the field of earthing technology, the results of extensive preliminary examinations have also been embodied in this standard. Many interesting results are available which are important for the earth electrodes, including those of lightning protection systems.

The fundamental processes leading to corrosion are explained below.

Practical anticorrosion measures especially for lightning protection earth electrodes shall be derived from this and from the wealth of material already acquired by the VDE task force on “Earth electrode materials”.

Terms used in corrosion protection and corrosion protection measurements

Corrosion

is the reaction of a metal material to its environment which leads to impairment of the characteristics of the metal material and/or its environment. The reaction is usually of electrochemical character.

Electrochemical corrosion

is corrosion during which electrochemical processes occur. They take place exclusively in the presence of an electrolyte.

Electrolyte

is an ion-conducting corrosive medium (e.g. soil, water, fused salts).

Electrode

is an electron-conducting material in an electrolyte. The system of electrode and electrolyte forms a half-cell.

Anode

is an electrode from which a d.c. current enters the electrolyte.

Cathode

is an electrode from which a d.c. current leaves the electrolyte.

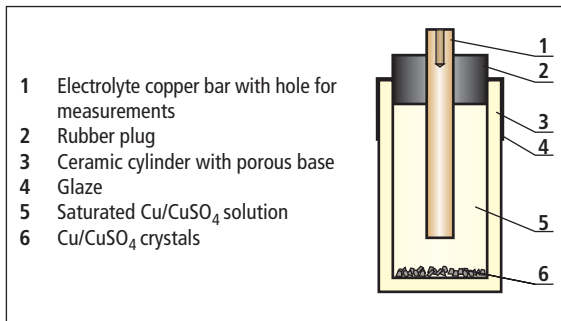


Fig. 5.5.7.1.1 Application example of a non-polarisable measuring electrode (copper/copper sulphate electrode) for tapping a potential within the electrolyte (cross-sectional view)

Reference electrode

is a measuring electrode for determining the potential of a metal in the electrolyte.

Copper sulphate electrode

is a reference electrode which can hardly be polarised, made of copper in saturated copper sulphate solution.

The copper sulphate electrode is the most common form of reference electrode for measuring the potential of subterranean metal objects (Figure 5.5.7.1.1).

Corrosion cell

is a voltaic cell with different local partial current densities for dissolving the metal. Anodes and cathodes of the corrosion cell can be formed

- ⇒ **on the material**
due to different metals (contact corrosion) or different structural components (selective or intercrystalline corrosion).
- ⇒ **on the electrolyte**
caused by different concentrations of certain materials having stimulatory or inhibitory characteristics for dissolving the metal.

Potentials

Reference potential

Potential of a reference electrode with respect to the standard hydrogen electrode.

Electropotential

is the electrical potential of a metal or an electron-conducting solid in an electrolyte.

5.5.7.2 Formation of voltaic cells, corrosion

The corrosion processes can be clearly explained with the help of a voltaic cell. If, for example, a metal rod is dipped into an electrolyte, positively charged ions pass into the electrolyte and conversely, positive ions are absorbed from the electrolyte from the metal band. In this context one speaks of the "solution pressure" of the metal and the "osmotic pressure" of the solution. Depending on the magnitude of these two pressures, either more of the metal ions from the rod pass into the solution (the rod therefore becomes negative compared to the solution) or the ions of the electrolyte collect in large numbers on the rod (the rod becomes positive compared to the electrolyte). A voltage is thus created between two metal rods in the electrolyte.

In practice, the potentials of the metals in the ground are measured with the help of a copper sulphate electrode. This consists of a copper rod dipped into a saturated copper sulphate solution (the reference potential of this reference electrode remains constant).

Consider the case of two rods made of different metals dipping into the same electrolyte. A voltage of a certain magnitude is now created on each rod in the electrolyte. A voltmeter can be used to

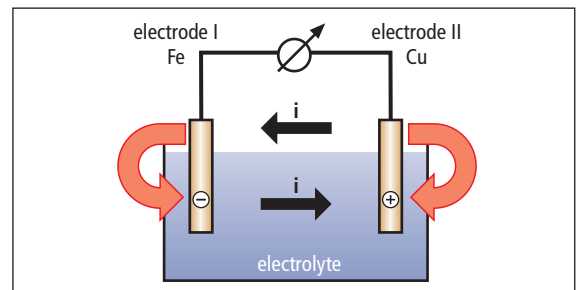


Fig. 5.5.7.2.1 Galvanic cell: iron/copper

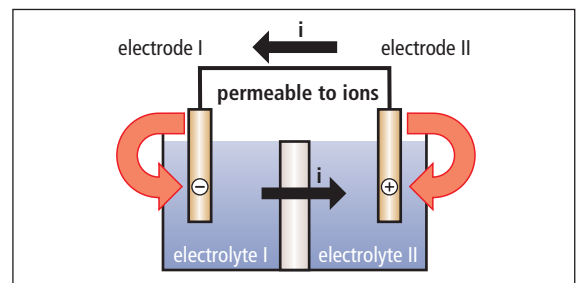


Fig. 5.5.7.2.2 Concentration cell

measure the voltage between the rods (electrodes); this is the difference between the potentials of the individual electrodes compared with the electrolyte.

How does it now come that current flows in the electrolyte and hence that material is transported, i.e. corrosion occurs?

If, as shown here, the copper and iron electrodes are connected via an ammeter outside the electrolyte, for example, the following (Figure 5.5.7.2.1) is ascertained: in the outer circuit, the current i flows from + to –, i.e. from the “nobler” copper electrode according to Table 5.5.7.2.1 to the iron electrode.

In the electrolyte, on the other hand, the current i must therefore flow from the “more negative” iron electrode to the copper electrode to close the circuit. As a generalisation, this means that the more negative pole passes positive ions to the electrolyte and hence becomes the anode of the voltaic cell, i.e. it dissolves. The dissolution of the metal occurs at those points where the current enters the electrolyte.

A corrosion current can also arise from a concentration cell (Figure 5.5.7.2.2). In this case, two electrodes made of the same metal dip into different electrolytes. The electrode in electrolyte II with the higher concentration of metal ions becomes electrically more positive than the other. Connecting

	Definition	Symbol(s)	Copper	Lead	Tin	Iron	Zinc
1	Free corrosion potential in the soil ¹⁾ [V]	$U_{M-Cu/CuSO_4}$	0 to –0.1	–0.5 to –0.6	–0.4 to –0.6 ²⁾	–0.5 to –0.8 ³⁾	–0.9 to –1.1 ⁵⁾
2	Cathodic protective potential in the soil ¹⁾ [V]	$U_{M-Cu/CuSO_4}$	–0.2	–0.65	–0.65 ²⁾	–0.85 ⁴⁾	–1.2 ⁵⁾
3	Electrochemical equivalent [kg/(A · year)]	$K = \frac{\Delta m}{I t}$	10.4	33.9	19.4	9.1	10.7
4	Linear corrosion rate [mm/year] at $J = 1 \text{ mA/dm}^2$	$W_{lin} = \frac{\Delta s}{t}$	0.12	0.3	0.27	0.12	0.15

¹⁾ Measured to saturated copper/copper sulphate electrode (Cu/Cu SO₄).

²⁾ Values are verified in presently performed tests. The potential of tin-coated copper depends on the thickness of the tin coating. Common tin coatings up to now have amounted up to a few µm and are thus between the values of tin and copper in the soil.

³⁾ These values do also apply to lower alloyed types of iron. The potential of steel in concrete (reinforcing iron of foundations) depends considerably on external influences. Measured to a saturated copper/copper sulphate electrode it generally amounts –0.1 to –0.4 V. In case of metal conductive connections with wide underground installations made of metal with more negative potential, it is cathodically polarised and thus reaches values up to approximately –0.5 V.

⁴⁾ In anaerobic soils the protective potential should be –0.95 V.

⁵⁾ Hot-dip galvanised steel, with a zinc coating according to the above mentioned table, has a closed external pure zinc layer. The potential of hot-dip galvanised steel in the soil corresponds therefore to approximately the stated value of zinc in the soil. In case of a loss of the zinc layer, the potential gets more positive. With its complete corrosion it can reach the value of steel.

The potential of hot-dip galvanised steel in concrete has approximately the same initial values. In the course of time, the potential can get more positive. Values more positive than approx. –0.75 V, however, have not been found yet.

Heavily hot-dip galvanised copper with a zinc layer of min. 70 µm has also a closed external pure zinc layer. The potential of hot-dip galvanised copper in soil corresponds therefore to approx. the stated value of zinc in soil. In case of a thinner zinc layer or a corrosion of the zinc layer, the potential gets more positive. Limit values have still not been defined yet.

Table 5.5.7.2.1 Potential values and corrosion rates of common metal materials

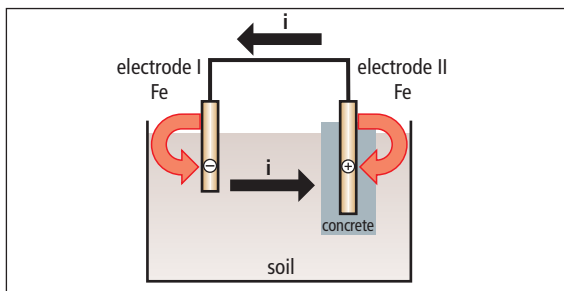


Fig. 5.5.7.2.3 Concentration cell: Iron in soil/iron in concrete

the two electrodes enables the current i to flow and the electrode, which is electrochemically more negative, dissolves.

A concentration cell of this type can be formed, for example, by two iron electrodes, one of which is fixed in concrete while the other lies in the ground (**Figure 5.5.7.2.3**).

Connecting these electrodes, the iron in the concrete becomes the cathode of the concentration cell and the one in the ground becomes the anode; the latter is therefore destroyed by ion loss.

For electrochemical corrosion it is generally the case that, the larger the ions and the lower their charge, the greater the transport of metal associated with the current flow i , (i.e. i is proportional to the atomic mass of the metal).

In practice, the calculations are carried out with currents flowing over a certain period of time, e.g. over one year. **Table 5.5.7.2.1** gives values which express the effect of the corrosion current (current density) in terms of the quantity of metal dissolved. Corrosion current measurements thus make it possible to calculate in advance how many grammes of a metal will be eroded over a specific period.

Of more practical interest, however, is the prediction if, and over which period of time, corrosion will cause holes or pitting in earth electrodes, steel tanks, pipes etc. So it is important whether the prospective current attack will take place in a diffuse or punctiform way.

For the corrosive attack, it is not solely the magnitude of the corrosion current which is decisive, but also, in particular, its density, i.e. the current per unit of area of the discharge area.

It is often not possible to determine this current density directly. In such cases, this is managed with potential measurements the extent of the avail-

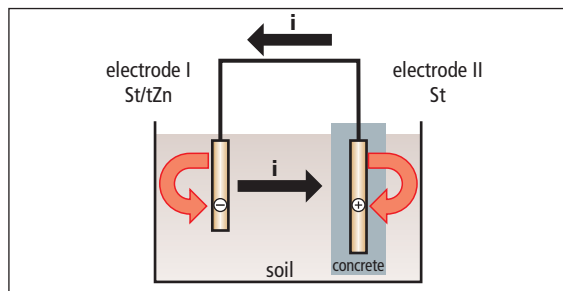


Fig. 5.5.7.2.4 Concentration cell: Galvanised steel in soil/steel (black) in concrete

able “polarisation” can be taken from. The polarisation behaviour of electrodes is discussed only briefly here.

Let us consider the case of a galvanised steel strip situated in the ground and connected to the (black) steel reinforcement of a concrete foundation (**Figure 5.5.7.2.4**). According to our measurements, the following potential differences occur here with respect to the copper sulphate electrode:

steel, (bare) in concrete: – 200 mV

steel, galvanised, in sand: – 800 mV

Thus there is a potential difference of 600 mV between these two metals. If they are now connected above ground, a current i flows in the outer circuit from reinforced concrete to the steel in the sand, and in the ground from the steel in the sand to the steel in the reinforcement.

The magnitude of the current i is now a function of the voltage difference, the conductance of the ground and the polarisation of the two metals.

Generally, it is found that the current i in the ground is generated by changes in the material.

But a change to the material also means that the voltage of the individual metals changes with respect to the ground. This potential drift caused by the corrosion current i is called polarisation. The strength of the polarisation is directly proportional to the current density. Polarisation phenomena now occur at the negative and positive electrodes. However, the current densities at both electrodes are mostly different.

For illustration, we consider the following example:

A well-insulated steel gas pipe in the ground is connected to copper earth electrodes.

If the insulated pipe has only a few small spots where material is missing, there is a higher current density at these spots resulting in rapid corrosion of the steel.

In contrast, the current density is low over the much larger area of the copper earth electrodes where the current enters.

Thus the polarisation is greater at the more negative insulated steel conductor than at the positive copper earth electrodes. The potential of the steel conductor is shifted to more positive values. Thus, the potential difference across the electrodes decreases as well. The magnitude of the corrosion current is therefore also a function of the polarisation characteristics of the electrodes.

The strength of the polarisation can be estimated by measuring the electrode potentials for a split circuit. The circuit is split in order to avoid the voltage drop in the electrolyte. Recording instruments are usually used for such measurements since there is frequently a rapid depolarisation immediately after the corrosion current is interrupted.

If strong polarisation is now measured at the anode (the more negative electrode), i.e. if there is an obvious shift to more positive potentials, then there is a high risk that the anode will corrode.

Let us now return to our corrosion cell-steel (bare) in concrete/steel, galvanised in the sand (**Figure 5.5.7.2.4**). With respect to a distant copper sulphate electrode, it is possible to measure a potential of the interconnected cells of between –200 mV and –800 mV. The exact value depends on the ratio of the anodic to cathodic area and the polarisability of the electrodes.

If, for example, the area of the reinforced concrete foundation is very large compared to the surface of the galvanised steel wire, then a high anodic current density occurs at the latter, so that it is polarised to almost the potential of the reinforcement steel and destroyed in a relatively short time. High positive polarisation thus always indicates an increased risk of corrosion.

In practice it is, of course, now important to know the limit above which a positive potential shifting means an acute risk of corrosion. Unfortunately, it is not possible to give a definite value, which applies in every case; the effects of the soil conditions alone are too various. It is, however, possible to stipulate fields of potential shifting for natural soils.

Summary:

A polarisation below +20 mV is generally non-hazardous. Potential shifts exceeding +100 mV are definitely hazardous. Between 20 and 100 mV there will always be cases where the polarisation causes considerable corrosion phenomena.

To summarise, one can stipulate:

The precondition for the formation of corrosion cells (voltaic cells) is always the presence of metal and electrolytic anodes and cathodes connected to be conductive.

Anodes and cathodes are formed from:

⇒ Materials

- different metals or different surface conditions of a metal (contact corrosion),
- different structural components (selective or intercrystalline corrosion),

⇒ Electrolytes

- different concentration (e.g. salinity, ventilation).

In corrosion cells, the anodic fields always have a more negative metal/electrolyte potential than the cathodic fields.

The metal/electrolyte potentials are measured using a saturated copper sulphate electrode mounted in the immediate vicinity of the metal in or on the ground. If there is a metal conductive connection between anode and cathode, then the potential difference gives rise to a d.c. current in the electrolyte which passes from the anode into the electrolyte by dissolving metal before entering again the cathode.

The “area rule” is often applied to estimate the average anodic current density J_A :

$$J_A = \frac{U_C - U_A}{\varphi_C} \cdot \frac{A_C}{A_A} \text{ in A/m}^2$$

J_A Average anodic current density

U_A, U_C Anode or cathode potentials in V

φ_C Specific polarisation resistance of the cathode in Ωm^2

A_A, A_C Anode or cathode surface m^2

The polarisation resistance is the ratio of the polarisation voltage and the total current of a mixed electrode (an electrode where more than one electrode reaction takes place).

In practice, it is indeed possible to determine the driving cell voltages $U_C - U_A$ and the size of the areas A_C and A_A as an approximation for estimating the rate of corrosion. The values for φ_A (specific polarisation resistance of the anode) and φ_C , however, are not available to a sufficient degree of accuracy. They depend on the electrode materials, the electrolytes and the anodic and cathodic current densities.

The results of examinations available until now allow the conclusion that φ_A is much smaller than φ_C .

To φ_C applies:

steel in the ground	approx. $1 \Omega m^2$
copper in the ground	approx. $5 \Omega m^2$
steel in concrete	approx. $30 \Omega m^2$

From the area rule, however, it is clear, that powerful corrosion phenomena occur both on enclosed steel conductors and tanks with small spots in the sheath where material is missing, connected to copper earth electrodes, and also on earthing conductors made of galvanised steel connected to extended copper earth-termination systems or extremely large reinforced concrete foundations.

By choosing suitable materials it is possible to avoid or reduce the risk of corrosion for earth electrodes. To achieve a satisfactory service life, material minimum dimensions must be maintained (Table 5.5.8.1).

5.5.7.3 Choice of earth electrode materials

Table 5.5.8.1 is a compilation of the earth electrode materials and minimum dimensions usually used today.

Hot-dip galvanised steel

Hot-dip galvanised steel is also suitable for embedding in concrete. Foundation earth electrodes, earth electrodes and equipotential bonding conductors made of galvanised steel in concrete may be connected with reinforcement iron.

Steel with copper sheath

In the case of steel with copper sheath, the comments for bare copper apply to the sheath material.

Damage to the copper sheath, however, creates a high risk of corrosion for the steel core, hence a complete closed copper layer must always be present.

Bare copper

Bare copper is very resistant due to its position in the electrolytic insulation rating. Moreover, in combination with earth electrodes or other installations in the ground made of more "base" materials (e.g. steel), it has additional cathodic protection, albeit at the expense of the more "base" metals.

Stainless steels

Certain high-alloy stainless steels according to EN 10088 are inert and corrosion-resistant in the ground. The free corrosion potential of high-alloy stainless steels in normally aerated soils is mostly close to the value of copper.

The surface of stainless steel earth electrode materials passivating within a few weeks, they are neutral to other (more inert and base) materials.

Stainless steels shall contain at least 16 % chrome, 5 % nickel and 2 % molybdenum.

Extensive measurements have shown that only a high-alloy stainless steel with the Material No. 1.4571, for example, is sufficiently corrosion-resistant in the ground.

Other materials

Other materials can be used if they are particularly corrosion-resistant in certain environments or are at least equally as good as the materials listed in Table 5.5.8.1.

5.5.7.4 Combination of earth electrodes made of different materials

The cell current density resulting from the combination of two different metals installed in the earth to be electrically conductive, leads to the corrosion of the metal acting as the anode (Table 5.5.7.4.1). This essentially depends on the ratio of the magnitude of the cathodic area A_C to the magnitude of the anodic area A_A .

The "Corrosion behaviour of earth electrode materials" research project has found the following with respect to the choice of earth electrode materials, particularly regarding the combination of different materials:

A higher degree of corrosion is only to be expected if the ratio of the areas is

$$\frac{A_C}{A_A} > 100$$

Generally, it can be assumed that the material with the more positive potential will become the cathode. The anode of a corrosion cell actually present can be recognised by the fact that it has the more negative potential when opening the metal conductive connection.

Connecting steel installations in the ground, the following earth electrode materials always behave as cathodes in (covering) soils:

- bare copper,
- tin-coated copper,
- high-alloy stainless steel.

Steel reinforcement of concrete foundations

The steel reinforcement of concrete foundations can have a very positive potential (similar to copper). Earth electrodes and earthing conductors connected directly to the reinforcement of large reinforced concrete foundations should therefore be made of stainless steel or copper.

This also applies particularly to short connecting cables in the immediate vicinity of the foundations.

Installation of isolating spark gaps

As already explained, it is possible to interrupt the conductive connection between systems with very different potentials installed in the ground by integrating isolating spark gaps. Normally, then it

is no longer possible for corrosion currents to flow. At upcoming surges, the isolating spark gap operates and interconnects the installations for the duration of the surges. However, isolating spark gaps must not be installed for protective and operating earth electrodes, since these earth electrodes must always be connected to the plant.

5.5.7.5 Other anticorrosion measures

Galvanised steel connecting cables from foundation earth electrodes to down conductors

Galvanised steel connecting cables from foundation earth electrodes to down conductors shall be laid in concrete or masonry up to above the surface of the earth.

If the connecting cables are led through the ground, galvanised steel must be equipped with concrete or synthetic sheathing or, alternatively, terminal lugs with NYY cable, stainless steel or fixed earthing terminals must be used.

Within the masonry, the earth conductors can also be led upwards without corrosion protection.

Earth entries made of galvanised steel

Earth entries made of galvanised steel must be protected against corrosion for a distance of at least 0.3 m above and below the surface of the earth.

Generally, bitumen coatings are not sufficient. Sheathing not absorbing moisture offers protection, e.g. butyl rubber strips or heat-shrinkable sleeves.

Underground terminals and connections

Cut surfaces and connection points in the ground must be designed to ensure that the corrosion resistance of the corrosion protection layer of the earth electrode material is the same for both. Connection points in the ground must therefore be equipped with a suitable coating, e.g. sheathed with an anticorrosive band.

Corrosive waste

When filling ditches and pits to install earth electrodes, pieces of slag and coal must not come into immediate contact with the earth electrode material; the same applies to construction waste.

Material with small area	Material with great area			
	Galvanised steel	Steel	Steel in concrete	Copper
Galvanised steel	+	+ zinc removal	–	–
Steel	+	+	–	–
Steel in concrete	+	+	+	+
Steel with Cu coating	+	+	+	+
Copper/StSt	+	+	+	+
+ combinable – not combinable				

Table 5.5.7.4.1 Material combinations of earth-termination systems for different area ratios ($A_C > 100 \times A_A$)

Material	Configuration	Min. dimensions			Notes
		Earth rod Ø mm	Earth conductor	Earth plate mm	
Copper	stranded ³⁾		50 mm ²		min. diameter of each strand 1.7 mm
	solid round material ³⁾		50 mm ²		diameter 8 mm
	solid flat material ³⁾		50 mm ²		min. thickness 2 mm
	solid round material	15 ⁸⁾			
	pipe	20			min. wall thickness 2 mm
	solid plate			500 x 500	min. thickness 2 mm
	grid-type plate			600 x 600	section 25 mm x 2 mm, min. length of grid construction: 4.8 m
Steel	galvanised solid round material ^{1), 2)}	16 ⁹⁾	diameter 10 mm		
	galvanised pipe ^{1), 2)}	25			min. wall thickness 2 mm
	galvanised solid flat material ¹⁾		90 mm ²		min. thickness 3 mm
	galvanised solid plate ¹⁾			500 x 500	min. thickness 3 mm
	galvanised grid-type plate ¹⁾			600 x 600	section 30 mm x 3 mm
	copper-plated solid round material ⁴⁾	14			min. 250 µm coating with 99.9 % copper
	bare solid round material ⁵⁾		diameter 10 mm		
	bare or galvanised solid flat material ^{5), 6)}		75 mm ²		min. thickness 3 mm
Stainless Steel ⁷⁾	solid round material	15	diameter 10 mm		
	solid flat material		100 mm ²		min. thickness 2 mm

1) The coating must be smooth, continuous and free of residual flux, mean value 50 µm for round and 70 µm for flat material.

2) Threads must be tapped before galvanising.

3) Can also be tin-coated.

4) The copper must be connected unresolvably with the steel.

5) Only permitted, if embedded completely in concrete.

6) Only permitted for the part of the foundation in contact with the earth, if connected safely with the reinforcement every 5 m.

7) Chrome ≥ 16 %, nickel ≥ 5 %, molybdenum ≥ 2 %, carbon ≤ 0,08 %.

8) In some countries 12 mm are permitted.

9) Some countries require earth lead-in rods to connect down conductor and earth electrode.

Table 5.5.8.1 Material, configuration and min. dimensions of earth electrodes according to IEC 62305-3 (EN 62305-3) Table 7

5.5.8 Materials and minimum dimensions for earth electrodes

Table 5.5.8.1 illustrates the minimum cross sections, shape and material of earth electrodes.

5.6 Electrical isolation of the external lightning protection system – Separation distance

There is a risk of uncontrolled flashovers between components of the external lightning protection system and metal and electrical installations within the structure, if there is insufficient distance between the air-termination or down-conductor system on one hand, and metal and electrical installations within the structure to be protected, on the other.

Metal installations such as water and air conditioning pipes and electric power lines, produce induction loops in the structure which are induced by impulse voltages due to the rapidly changing magnetic lightning field. These impulse voltages must be prevented from causing uncontrolled flashovers which can also possibly cause a fire. Flashovers on electric power lines, for example, can cause enormous damage to the installation and the connected consumers. **Figure 5.6.1** illustrates the principle of separation distance. The formula for calculating the separation distance is difficult for the practitioner to apply.

The formula is:

$$s = k_i \frac{k_c}{k_m} \cdot l(m)$$

- k_i is a function of the class of lightning protection system chosen (induction factor),
- k_c is a function of the geometric arrangement (current splitting coefficient),
- k_m is a function of the material in the point of proximity (material factor) and
- $l(m)$ is the length of the air-termination system or down-conductor system from the point at which the separation distance shall be determined to the next point of equipotential bonding.

The coefficient k_i (induction factor) of the corresponding class of lightning protection system represents the threat from the steepness of the current.

Factor k_c takes into consideration the splitting of the current in the down-conductor system of the external lightning protection system. The standard gives different formulae for determining k_c . In order to achieve the separation distances which still can be realised in practice, particularly for higher structures, it is recommended to install ring conductors, i.e. to intermesh the down conductors. This intermeshing balances the current flow, which reduces the required separation distance.

The material factor k_m takes into consideration the insulating characteristics of the surroundings. This calculation assumes the electrical insulating characteristics of air to be a factor of 1. All other solid materials used in the construction industry (e.g. masonry, wood, etc.) insulate only half as well as air.

Further material factors are not given. Deviating values must be proved by technical tests. A factor of 0.7 is specified for the GRP material (glass-fibre reinforced plastic) used in the products of the isolated air-termination systems from DEHN + SÖHNE (DEHNiso distance holder, DEHNiso Combi). This

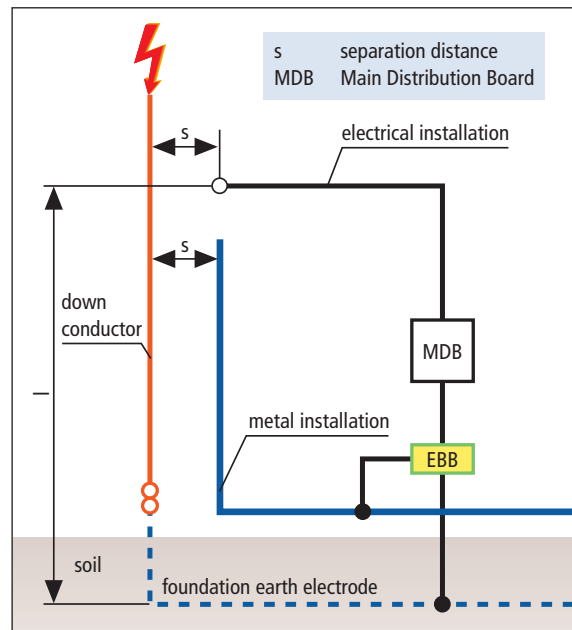


Fig. 5.6.1 Illustration – Separation distance

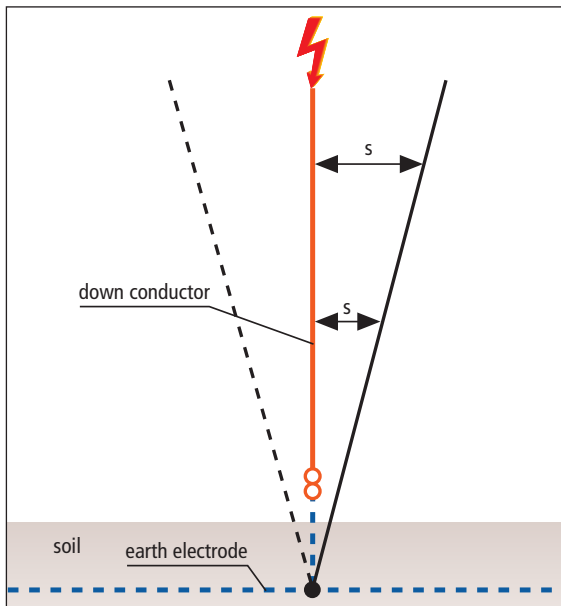


Fig. 5.6.2 Potential difference with increasing height

factor can be used for calculation in the same way as the other material factors.

Length l is the actual length along the air-termination system or down-conductor system from the point at which the separation distance to the next point of equipotential bonding or the next lightning equipotential bonding level shall be determined.

Each structure with lightning equipotential bonding has an equipotential surface of the foundation earth electrode or earth electrode near the surface of the earth. This surface is the reference plane for determining the distance l .

If a lightning equipotential bonding level is to be created for high structures, then for a height of 20 m, for example, the lightning equipotential bonding must be carried out for all electrical and electronic conductors and all metal installations. The lightning equipotential bonding must be realised by using **surge protective devices Type I**.

Otherwise, even for high structures, the equipotential surface of the foundation earth electrode/earth electrode shall be used as reference point and basis for the length l . Higher structures

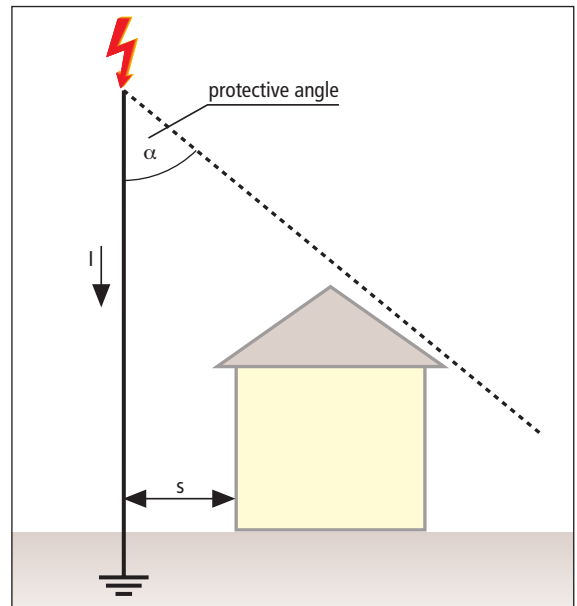


Fig. 5.6.3 Air-termination mast with $k_c = 1$

are making it more and more difficult to maintain the required separation distances.

The potential difference between the structure's installations and the down conductors is equal to zero near the earth's surface. The potential difference increases with increasing height. This can be imagined as a cone standing on its tip (**Figure 5.6.2**).

Hence, the separation distance to be maintained is greatest at the tip of the building or on the surface of the roof and becomes less towards the earth-termination system.

This requires a multiple calculation of the distance from the down conductors with a different distance l .

The calculation of the current splitting coefficient k_c is often difficult because of the different structures.

If a single air-termination rod is erected next to the structure, for example, the total lightning current flows in this one air-termination conductor and down conductor. Factor k_c is therefore equal to 1.

The lightning current cannot split here. Therefore it is often difficult to maintain the separation dis-

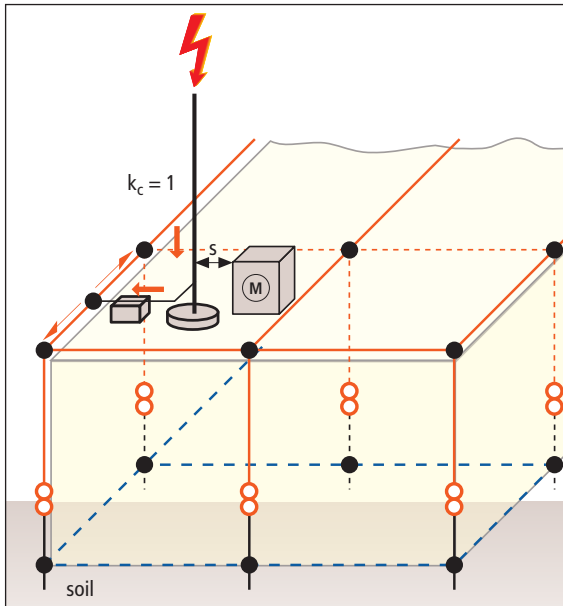


Fig. 5.6.4 Flat roof with air-termination rod and ventilation outlet

tance. In **Figure 5.6.3**, this can be achieved by erecting the mast further away from the structure. Almost the same situation occurs for air-termination rods e.g. for roof-mounted structures. Until it reaches the next connection of the air-termination rod to the air-termination or down conductor. This defined path carries 100 % ($k_c = 1$) of the lightning current (**Figure 5.6.4**).

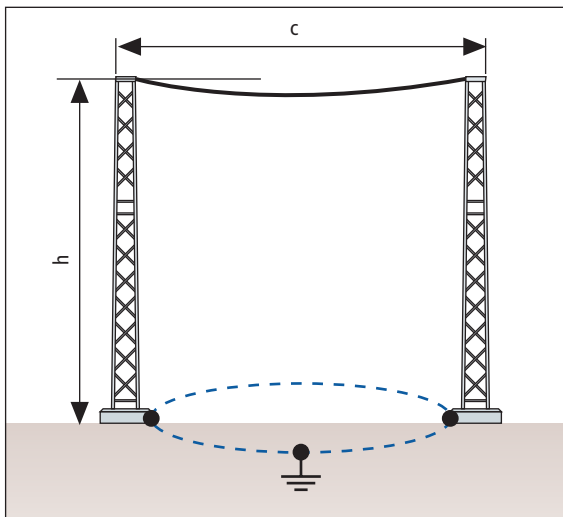


Fig. 5.6.5 Determination of k_c with two masts with overspanned cable and an earth electrode Type B

If two air-termination rods or air-termination masts have a cable spanned between them, the lightning current can split between two paths (**Figure 5.6.5**). Owing to the different impedances, however, the splitting is not always 50 % to 50 %, since the lightning flash does not always strike the exact centre of the arrangement but can also strike along the length of the air-termination system.

The most unfavourable case is taken into account by calculating the factor k_c in the formula.

This calculation assumes an earth-termination system Type B. If single earth electrodes Type A are existing, these must be interconnected.

$$k_c = \frac{h + c}{2h + c}$$

h length of the down conductor

c mutual distance of the air-termination rods or air-termination masts

The following example illustrates the calculation of the coefficient for a gable roof with two down conductors (**Figure 5.6.6**). An earth-termination system Type B (ring or foundation earth electrode) is existing.

$$k_c = \frac{9 + 12}{2 \cdot 9 + 12} = 0.7$$

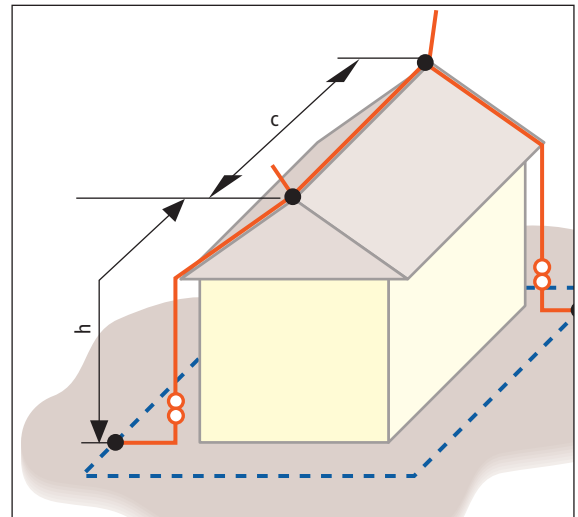


Fig. 5.6.6 Determination of k_c for a gable roof with 2 down conductors

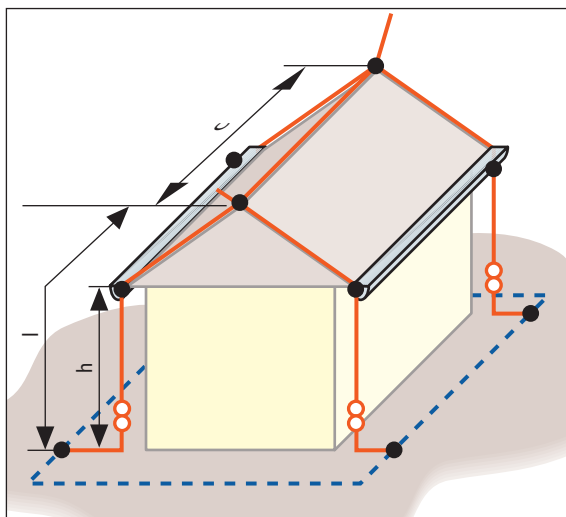


Fig. 5.6.7 Gable roof with 4 down conductors

The arrangement of the down-conductor system shown in **Figure 5.6.6** should no longer be installed, not even on a detached house either. The current splitting coefficient is significantly improved by using two further down conductors, i.e. a total of 4 (**Figure 5.6.7**). The following formula is used in the calculation:

$$k_c = \frac{1}{2n} + 0.1 + 0.2 \sqrt[3]{\frac{c}{h}}$$

- h length of the down conductor up to the eaves gutter of the building as worst point for a lightning input
- c mutual distance of the down conductors
- n is the total number of down conductors

$$k_c = \frac{1}{2 \cdot 4} + 0.1 + 0.2 \sqrt[3]{\frac{12}{4}}$$

Result: $k_c \approx 0.51$

For structures with flat roofs, the current splitting coefficient is calculated as follows. In this case, an earth electrode arrangement Type B is a precondition (**Figure 5.6.8**).

$$k_c = \frac{1}{2n} + 0.1 + 0.2 \sqrt[3]{\frac{c}{h}}$$

- h plumb distance, height of the building
- c mutual distance of the down conductors
- n the total number of down conductors

The distances of the down conductors are assumed to be equal. If not, c is the greatest distance.

If electrical structures or domelights are located on the flat roof (**Figure 5.6.9**), then two current splitting coefficients must be taken into account when calculating the separation distance. For the air-termination rod, $k_c = 1$ to the next air-termination/down conductor.

The calculation of the current splitting coefficient k_c for the subsequent course of the air-termination system and down conductors is performed as explained above. For illustration, the separation distance s for a flat roof with roof-mounted structures is determined below.

Example:

Domelights were installed on a structure with a lightning protection system Class III. They are controlled electrically.

Structure data:

- ⇒ Length 40 m
- Width 30 m
- Height 14 m
- ⇒ Earth-termination system, foundation earth electrode Type B
- ⇒ Number of down conductors: 12
- ⇒ Distance of the down conductors:
min. 10 m
max. 15 m
- ⇒ Height of the electrically controlled dome-lights: 1.5 m

The calculation of the current splitting coefficient k_c for the structure is:

$$k_c = \frac{1}{2 \cdot 12} + 0.1 + 0.2 \sqrt[3]{\frac{15}{14}}$$

Result: $k_c \approx 0.35$

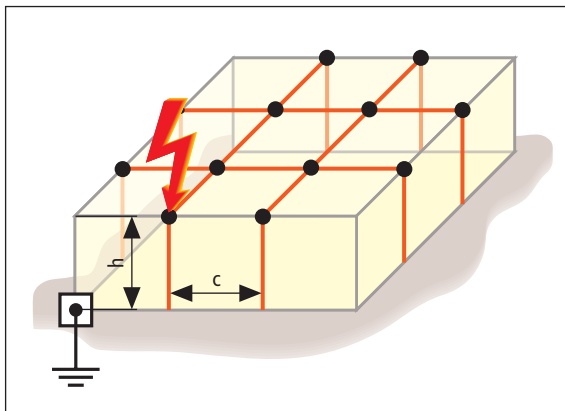


Fig. 5.6.8 Value of coefficient k_c in case of a meshed network of air-termination conductors and an earthing Type B

It is not necessary to calculate the factor k_c for the air-termination rod $k_c = 1$.

For the calculation of the current splitting the air-termination rod is assumed to be positioned at the edge of the roof and not within the mesh of the air-termination system. If the air-termination rod is within the mesh, the current splitting and the shortest length in the mesh has to be considered additionally.

Calculation of the separation distance for the top edge of the roof of the structure:

The material factor k_m is set as for solid building material $k_m = 0.5$.

$$s = 0.04 \frac{0.35}{0.5} 14(m)$$

Result: $s \approx 0.39 \text{ m}$

Calculation of the separation distance for the air-termination rod:

The material factor is $k_m = 0.5$ because of the position of the air-termination rod on the flat roof.

$$s = 0.04 \frac{1}{0.5} 1.5(m)$$

Result: $s = 0.12 \text{ m}$

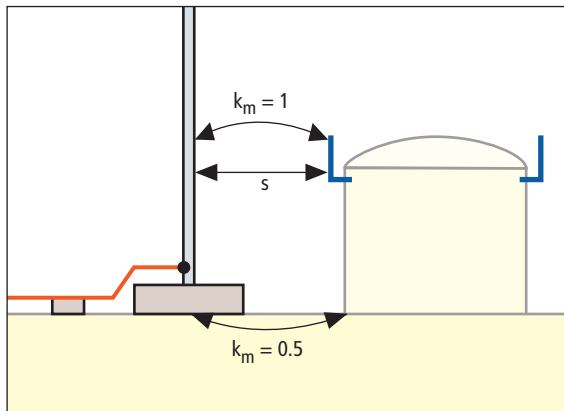


Fig. 5.6.9 Material factors of an air-termination rod on a flat roof

This calculated separation distance would be correct if the air-termination rod were erected on the surface of the earth (lightning equipotential bonding level).

In order to obtain the separation distance completely and correctly, the separation distance of the structure must be added.

$$\begin{aligned} S_{\text{tot}} &= s_{\text{structure}} + s_{\text{air-termination rod}} \\ &= 0.39 \text{ m} + 0.12 \text{ m} \end{aligned}$$

$$S_{\text{tot}} = 0.51 \text{ m}$$

This calculation states that a separation distance of 0.51 m must be maintained at the uppermost point of the domelight. This separation distance was determined using the material factor 0.5 for solid materials.

Erecting the air-termination rod with a concrete base, the "full insulating characteristics" of the air are not available at the foot of the air-termination rod (Figure 5.6.9). At the foot of the concrete base a separation distance of $s_{\text{structure}} = 0.39$ (solid material) is sufficient.

If lightning equipotential bonding levels are created for high structures at different heights by integrating all metal installations and all electrical and electronic conductors by means of lightning current arresters (SPD Type I), then the following calculation can be carried out. This involves calculating distances to conductors installed on only one lightning equipotential bonding level, and also to those installed over several levels.

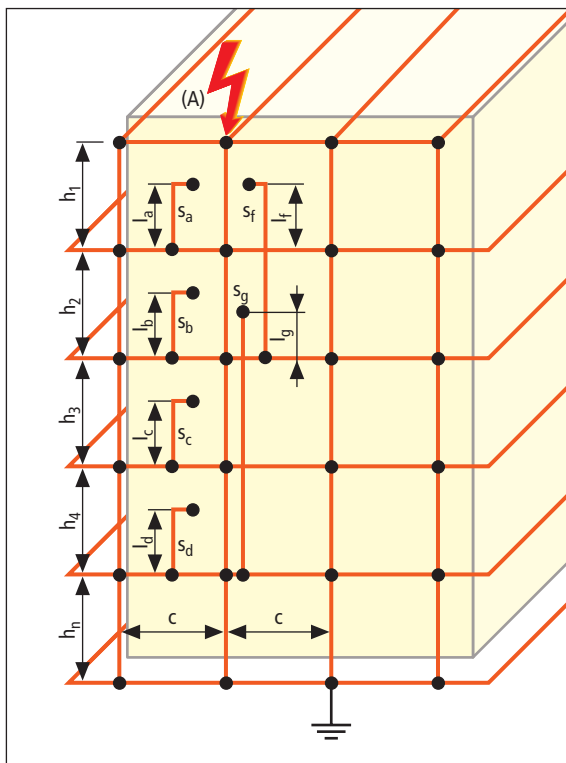


Fig. 5.6.10 Value of coefficient k_c in case of an intermeshed network of air-termination, ring conductors interconnecting the down conductors and an earthing Type B

This assumes an earth-termination system in form of a foundation or ring earth electrode (Type B) or a meshed network (**Figure 5.6.10**).

As previously explained, supplementary ring conductors can be installed around the structure (truss) to balance the lightning current. This has a positive effect on the separation distance. **Figure 5.6.10** illustrates the principle of ring conductors around the structure, without installing a lightning equipotential bonding level by using lightning current arresters at the height of the ring conductors.

The individual segments are assigned different current splitting coefficients k_c . If the separation distance for a roof-mounted structure shall now be determined, the total length from the equipotential surface of the earth electrode to the uppermost tip of the roof-mounted structure must be used as the base (sum of the partial lengths). If the

total separation distance s_{tot} is to be determined, the following formula must be used for the calculation:

$$s_{tot} = \frac{k_i}{k_m} (k_l \cdot l_{tot} + k_{c3} \cdot l_3 + k_{c4} \cdot l_4)$$

With this design of supplementary ring conductors around the structure, it is still the case that no partial lightning currents whatsoever are conducted into the structure.

Even if the numerous down conductors and supplementary ring conductors do not allow a maintaining of the separation distance for the complete installation, it is possible to define the upper edge of the structure as the lightning equipotential bonding surface (+/-0). This roof-level lightning equipotential bonding surface is generally implemented for extremely high structures where it is physically impossible to maintain the separation distance.

This requires the integration of all metal installations and all electrical and electronic conductors into the equipotential bonding by means of lightning current arresters (SPD Type I). This equipotential bonding is also directly connected to the external lightning protection system. These previously described measures allow to set the separation distances on the upper edge of the structure to 0. The disadvantage of this type of design is that all conductors, metal installations, e.g. reinforcements, lift rails and the down conductors as well, carry lightning currents. The effect of these currents on electrical and electronic systems must be taken into account when designing the internal lightning protection system (surge protection). It is advantageous to split the lightning current over a large area.

5.7 Step and touch voltages

IEC 62305-3 (EN 62305-3) draws attention to the fact that, in special cases, touch or step voltages outside a structure in the vicinity of the down conductors can present a life hazard even though the lightning protection system was designed according to the latest standards.

Special cases are, for example, the entrances or canopies of structures frequented by large num-

bers of people such as theatres, cinemas, shopping centres, where bare down conductors and earth electrodes are present in the immediate vicinity.

Structures which are particularly exposed (at risk of lightning strikes) and freely accessible to members of the public may also be required to have measures preventing intolerably high step and touch voltages.

These measures (e.g. potential control) are primarily applied to steeples, observation towers, mountain huts, floodlight masts in sports grounds and bridges.

Gatherings of people can vary from place to place (e.g. in shopping centre entrances or in the staircase of observation towers). Measures to reduce step and touch voltages are therefore only required in the areas particularly at risk.

Possible measures are potential control, isolation of the site or the additional measures described below. The individual measures can also be combined with each other.

Definition of touch voltage

Touch voltage is a voltage acting upon a person between his position on the earth and when touching the down conductor.

The current path leads from the hand via the body to the feet (Figure 5.7.1).

For a structure built with a steel skeleton or reinforced concrete, there is no risk of intolerably high touch voltages provided that the reinforcement is safely interconnected or the down conductors are installed in concrete.

Moreover, the touch voltage can be disregarded for metal facades if they are integrated into the equipotential bonding and/or used as natural components of the down conductor.

If there is a reinforced concrete with a safe tying of the reinforcement to the foundation earth electrode under the surface of the earth in the areas outside the structure which is at risk, then this measure already improves the curve of the gradient area and acts as a potential control. Hence step voltage can be left out of the considerations.

The following measures can reduce the risk of someone being injured by touching the down conductor:

- ⇒ The down conductor is sheathed in insulating material (min. 3 mm crosslinked polyethylene with an impulse withstand voltage of 100 kV 1.2/50 μ s).
- ⇒ The position of the down conductors can be changed, e.g. not in the entrance of the structure.
- ⇒ The probability of people accumulating can be reduced with information or prohibition signs; barriers can also be used.
- ⇒ The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down conductor must be not less than 5000 Ω m.

A layer of asphalt with a thickness of 5 cm, generally meets this requirement.

- ⇒ Compression of the meshed network of the earth-termination system by means of potential control.

Note

A downpipe, even if it is not defined as a down conductor, can present a hazard to persons touch-

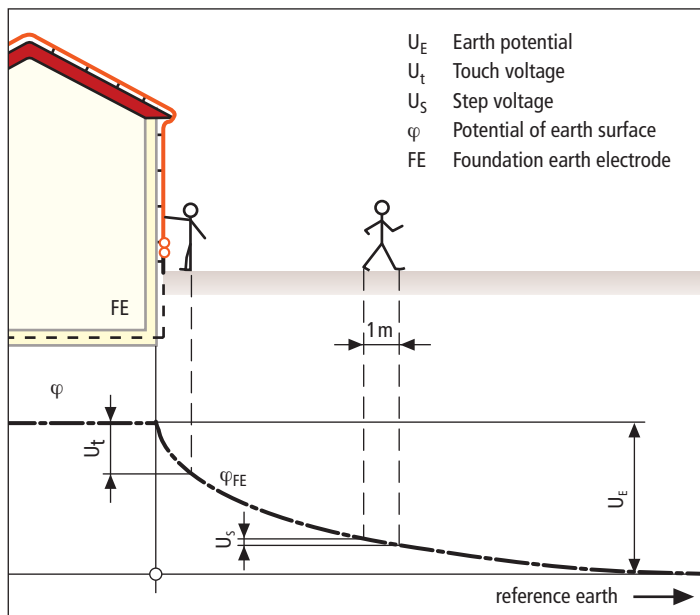


Fig. 5.7.1 Illustration of touch voltage and step voltage

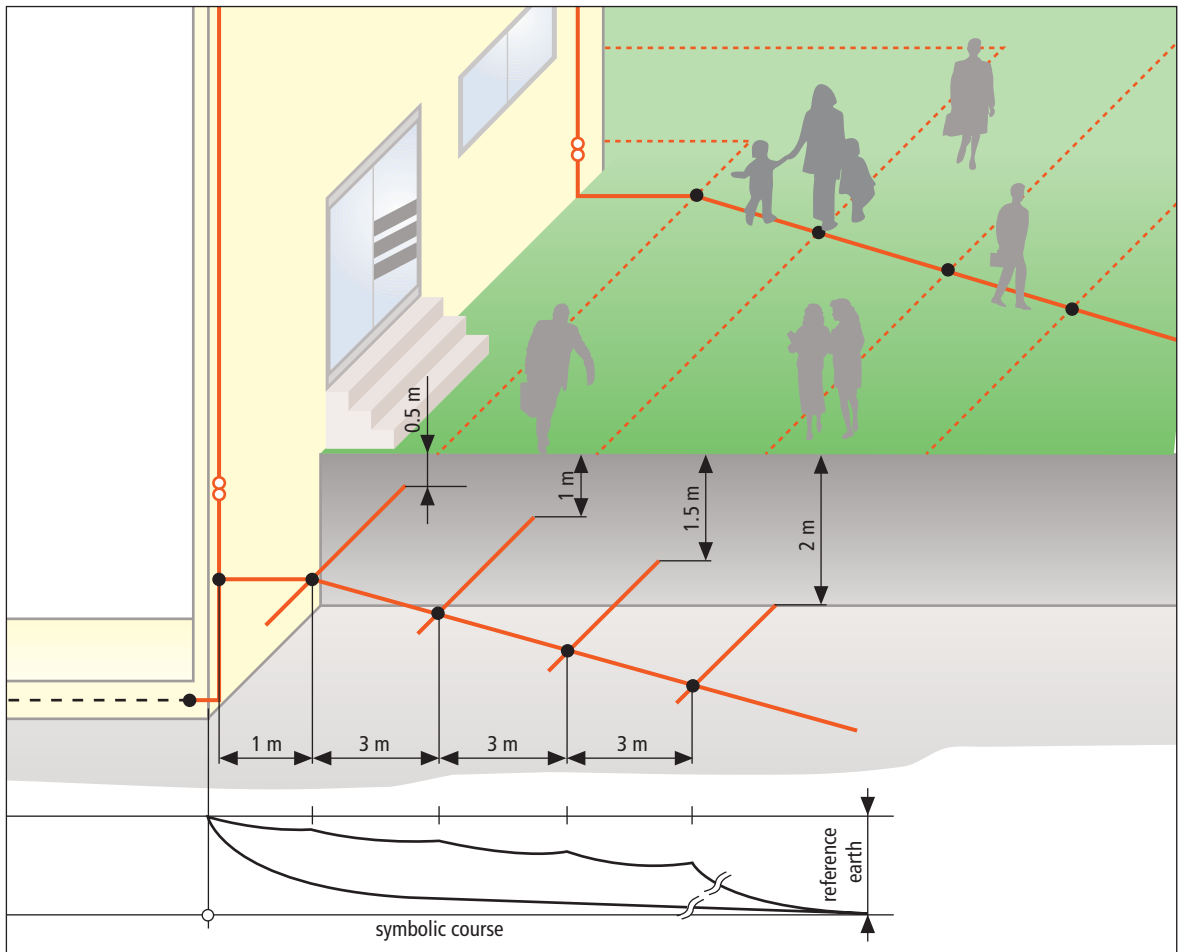


Fig. 5.7.2 Potential control – Illustration and symbolic course of the gradient area

ing it. In such a case, one possibility is to replace the metal pipe with a PVC one (height: 3 m).

Definition of step voltage

Step voltage is a part of the earthing potential which can be bridged by a person taking a step over 1 m. The current path runs via the human body from one foot to the other (Figure 5.7.1).

The step voltage is a function of the form of the gradient area.

As is evident from the illustration, the step voltage decreases as the distance from the structure increases. The risk to persons therefore decreases the more they are away from the structure.

The following measures can be taken to reduce the step voltage:

- ⇒ Persons can be prevented from accessing the hazardous areas (e.g. by barriers or fences)
- ⇒ Reducing the mesh size of the earthing installation network – potential control
- ⇒ The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down-conductor system must be not less than $5000 \Omega\text{m}$.

A layer of asphalt with a thickness of 5 cm, or a 15 cm thick bed of gravel generally meets this requirement

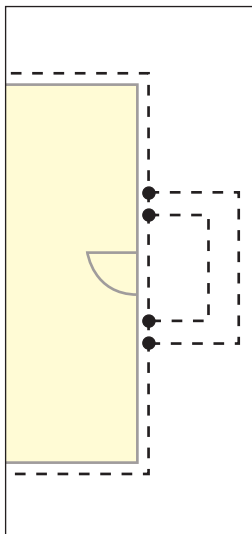


Fig. 5.7.3 Possible potential control in entrance area of the building

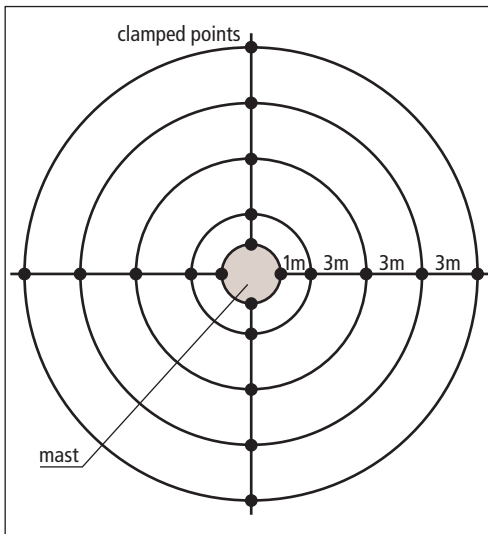


Fig. 5.7.4 Potential control performance for a flood light or cell site mast

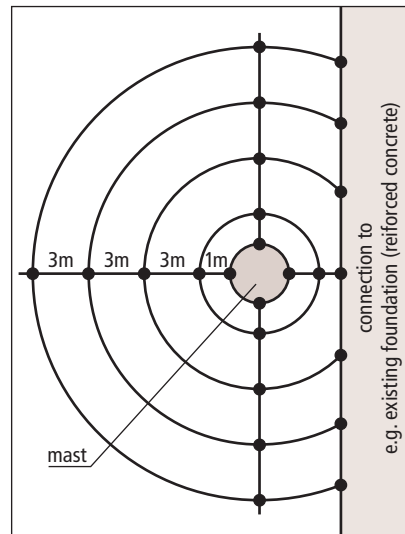


Fig. 5.7.5 Connection control at the ring/foundation earth electrode

If a large number of people frequently congregate in a hazardous area near to the structure to be protected, then a potential control must be provided to protect them.

The potential control is sufficient if the resistance gradient on the surface of the earth in the field to be protected does not exceed $1 \Omega/\text{m}$.

To achieve this, an existing foundation earth electrode should be supplemented by a ring earth electrode installed at a distance of 1 m and a depth of 0.5 m. If the structure already has an earth-termination system in form of a ring earth electrode, this is already “the first ring” of the potential control.

Additional ring earth electrodes should be installed at a distance of 3 m from the first one and

the subsequent ones. The depth of the ring earth electrode shall be increased (in steps of 0.5 m) the more it is away from the structure (see **Table 5.7.1**).

If a potential control is implemented for a structure, it must be installed as follows (**Figure 5.7.2** and **5.7.3**):

The down conductors must be connected to all the rings of the potential control.

The individual rings must be connected at least twice, however (**Figure 5.7.4**).

If ring earth electrodes (control earth electrodes) cannot be designed to be circular, their ends must be connected to the other ends of the ring earth electrodes. There should be at least two connections within the individual rings (**Figure 5.7.5**).

	Distance from the building	Depth
1 st ring	1 m	0.5 m
2 nd ring	4 m	1.0 m
3 rd ring	7 m	1.5 m
4 th ring	10 m	2.0 m

Table 5.7.1 Ring distances and depths of the potential control

When choosing the materials for the ring earth electrodes, attention must be paid to the possible corrosion load (Chapter 5.5.7).

Stainless steel V4A (Material No. 1.4571) has proved to be a good choice for taking the formation of voltaic cells between foundation and ring earth electrodes into account.

Cables \varnothing 10 mm or flat strips 30 mm x 3.5 mm can be installed as ring earth electrodes.

5.7.1 Control of the touch voltage at down conductors of lightning protection systems

The hazardous area of touch and step voltages for persons outside of a building is within the distance of 3 m to the building and up to a height of 3 m. This height of the area to be protected corresponds to the level which a person can reach with his hand plus an additional separation distance s (Figure 5.7.1.1).

Special measures of protection are required, for example, for the entrances or canopies of structures highly frequented such as theatres, cinemas, shopping centres, kindergartens where non-insulated down conductors and earth electrodes are nearby.

Structures which are particularly exposed (at risk of lightning strikes) and freely accessible to members of the public, for example mountain huts, may also be required to have measures preventing intolerably high touch voltages. Moreover life hazard is considered as parameter L1 (injury or death of persons) in the risk analyse of a structure according to IEC 62305-2 (EN 62305-2).

The following measures can reduce the risk of touch voltage:

- ⇒ The down conductor is sheathed in insulating material (min. 3 mm polymerised polyethylene

with an impulse withstand voltage of 100 kV (1.2/50 μ s).

- ⇒ The position of the down conductors is changed, (e.g. down conductors are not installed in the entrance of the structure).
- ⇒ The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down conductor is at least 5 k Ω m.
- ⇒ The probability of people accumulating can be reduced by information or prohibition signs; barriers can also be used.

The measures of protection against touch voltage may be insufficient with regard to an effective protection of people. The required high-voltage resistant coating of an exposed down conductor, for example is not enough if there are no additional measures of protection against creep-flashovers at the surface of the insulation. This is particularly important if environmental influences such as rain (humidity) are to be considered.

Just like at a bare down conductor, high voltages occurs at an insulated down conductor in case of a lightning strike. This voltage, however, is separated from people by the insulation. The human body being a very good conductor compared with the insulator, the insulating layer is stressed by almost the whole touch voltage. If the insulation does not cope with the voltage, part of the lightning current might flow to the earth via the human body as in case of the bare down conductor. Safe protection against life hazard due to touch voltage requires to prevent from flashover through the insulation and from creep-flashovers along the insulation.

A balanced system solution as provided by the CUI conductor meets these requirements of electric

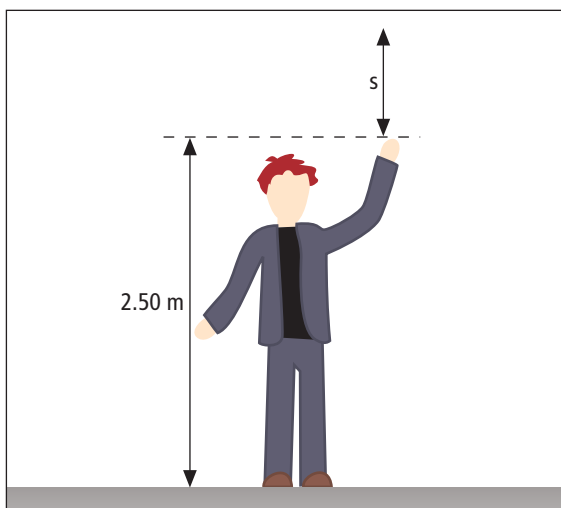


Fig. 5.7.1.1 Area to be protected for a person

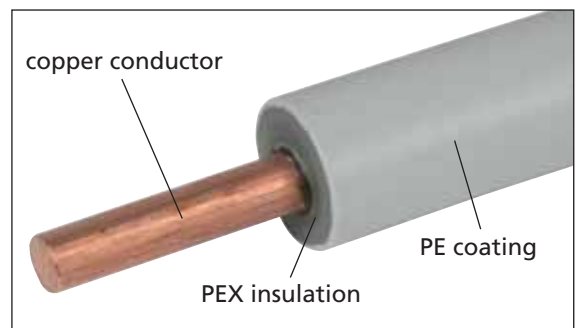


Fig. 5.7.1.2 Structure of the CUI conductor



Fig. 5.7.1.3 Withstand voltage test under sprinkling

strength and creep-flashover insulation to protect against touch voltage.

Structure of the CUI conductor

A copper conductor with a cross section of 50 mm² is coated with an insulating layer of surge proof cross-linked polyethylene (PEX) of approx. 6 mm thickness (Figure 5.7.1.2).

The insulated conductor has an additional thin polyethylene (PE) layer for protection against external influences. The insulated down conductor CUI is installed vertically in the whole hazard area,

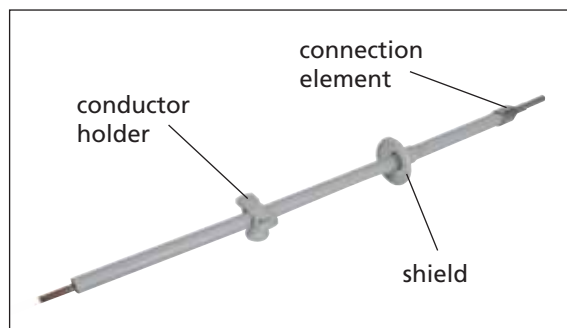


Fig. 5.7.1.4 CUI conductor

i.e. from the earth surface level up to a height of 3 m. The upper end of the conductor is connected to the down conductor coming from the air-termination system, the lower end to the earth-termination system.

Not only the electric strength of the insulation but also the risk of creep-flashovers between the terminal point at the bare down conductor and the hand of the touching person has to be considered. This problem of creeping discharges, well-known in high voltage engineering, is getting worse in case of rain, for example. Tests have shown that under sprinkling the flashover distance can be more than 1 m at an insulated down conductor without additional measures. A suitable shield on the insulated down conductor keeps the CUI conductor dry enough to avoid a creep-flashover along the insulating surface. The operating safety of the CUI conductor with regard to the electric strength and the resistance against creep-flashovers at impulse voltages up to 100 kV (1.2/50 µs) has been tried and tested in withstand voltage tests under sprinkling conditions according to IEC 60060-1. At these sprinkling tests water of a certain conductivity and quantity is sprinkled on the conductor in an angle of approx. 45 ° (Figure 5.7.1.3).

The CUI conductor is prefabricated with connection element to be connected to the down conductor (inspection joint) and can be shortened on site if necessary for being connected to the earth-termination system. The product is available in lengths of 3.5 m or 5 m and with the necessary plastic or metal conductor holders (Figure 5.7.1.4). By the special CUI conductor the touch voltage at down conductors can be controlled with easy measures and little installation work. Hence the damage risk for persons in special areas will be considerably reduced.

Inductive coupling at a very great steepness of current

Regarding the damage risk for persons also the magnetic field of the arrangement with its influence on the closer surrounding of the down conductor has to be considered. In extended installation loops, for example, voltages of several 100 kV can occur near the down conductor which can result in high economic losses. Also the human body, due to its conductivity, together with the down conductor and the conductive earth, forms a

loop having a mutual inductance of M where high voltages U_i can be induced (Figures 5.7.1.5a and 5.7.1.5b). In this case the system arrester-person has the effect of a transformer.

This coupled voltage arises at the insulation, the human body and the earth being primarily considered as conductive. The voltage load becoming too high it results in a puncture or creeping flash-over. The induced voltage then drives a current through this loop, the magnitude of which depends on the resistances and the self-inductance of the loop and means life hazard for the person concerned. Hence the insulation must withstand this voltage load. The normative specification of 100 kV at 1.2/50 μ s includes the high but very short voltage impulses which are only applied as long as the current rises (0.25 μ s in case of a negative subsequent lightning strike). The deeper the insulated down conductors are buried, the greater is the loop and thus the mutual inductance. Hence the induced voltage and the loading of the insulation increases correspondingly which also has to be taken into account with regard to the inductive coupling.

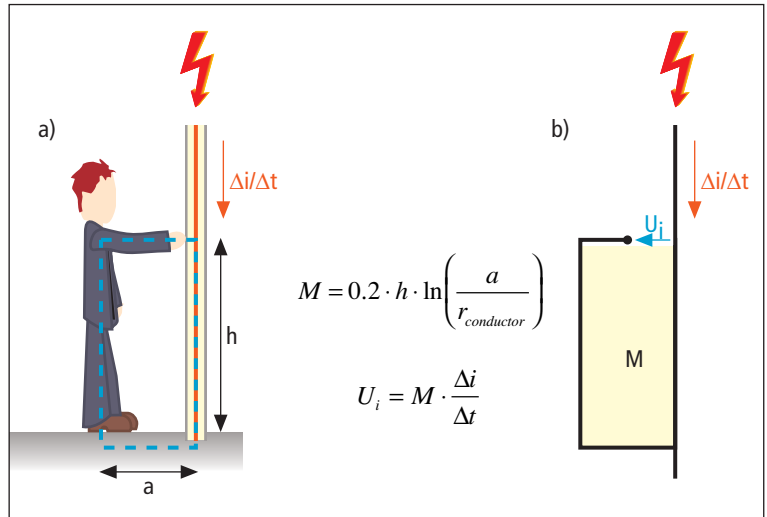


Fig. 5.7.1.5 (a) Loop formed by conductor and person
(b) Mutual inductance M and induced voltage U_i