Lightning Protection, Surge Protection and Earthing System

1.0 INTRODUCTION

Lightning is one of nature's most powerful and destructive phenomena. Lightning discharges contain awesome amounts of electrical energy and have been measured from several thousand amps to over 200,000 amps. Even though a lightning discharge is of a very short duration, typically 200 microseconds, it is a very real cause of damage and destruction.

The effects of a direct strike are obvious and immediately apparent such as buildings damaged, trees blown apart, personal injuries and even death. However, the secondary effects of lightning can caused overall performance of electronic systems severely affected by lightning induced transients and switching actions, which give rise to transient over voltages or surges.

A reliable lightning protection scheme must encompass both structural lightning protection and transient over voltage (electronic systems) protection.

2.0 LIGHTNING STATISTIC

The major role of lightning protection is to secure a structure from lightning damage by intercepting flashes and guiding their currents to the ground. Since lightning tends to strike at the highest object in the vicinity, rods are typically placed at the apex of a structure and along its ridges; low-impedance copper conductor connects them to the ground.

The isoceraunic map (lightning threats map) shown in Figure 1 below will depict the number of lightning days per year where Malaysia stands as the world's number 2 lightning hotspot and with an average of 240 lightning days per annum which is about 40 strikes per square kilometer per year.

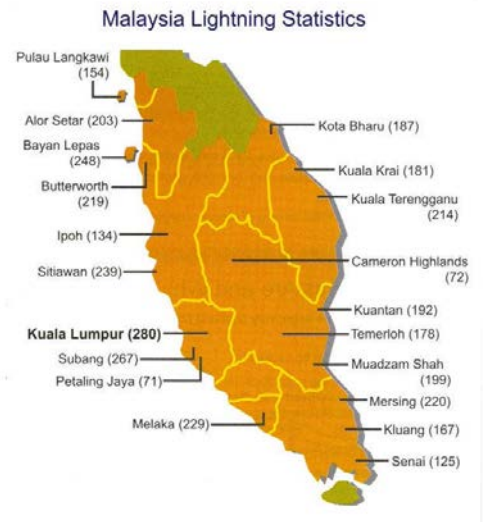


Figure 1: Malaysia Lightning Statistics
*Source: Meteorological Department, Malaysia
** ( ) denotes the number of lightning days per year

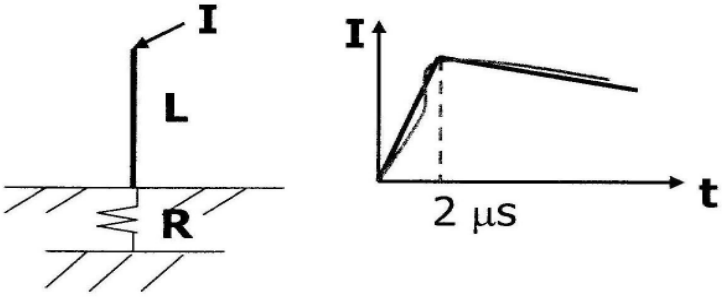
3.0 EFFECTS OF LIGHTNING STRIKE

3.1. Electrical Effects

Main cause of lightning damage is HIGH CURRENT which in turn causes HIGH VOLTAGES to arise on strickened or affected objects.

As the current is discharged through the resistance of the earth electrode of the lightning protection system, it produces a resistive voltage drop which may momentarily raise the potential of the protection system to a high value relative to true earth. It may also produce around the earth electrode a high potential gradient dangerous to people and animals.

The resulting voltage drop in the protection system is therefore the arithmetic sum of the resistive and inductive voltage components. It can be derived by referring to a simplified example as shown below:



Where the values given are:

I = 20kA (over 75% of lightning strokes have currents greater than this)
R= 10 ohms, resistance or earth connection
L= 20mH, inductance of tower

Tower top: Voltage $V_{tt} = IR + L\frac{dI}{dt} = 20 \text{ x } 10 + 20 \text{ x } 10^{-6}\frac{20}{2\times10^{-6}}$

$= 200 \text{ kV} + 200 \text{ kV} = \underline{400 \text{ kV}}$

Tower footing: Voltage $V_f = IR = 20 \text{ x } 10 = \underline{200 \text{ kV}}$!!!

ie. VERY HIGH VOLTAGES ARE CAUSED

3.2 Side-flashing

When a lightning protection system is struck, its electrical potential with respect to earth is raised and, unless suitable precautions are taken, the discharge may seek alternative paths to earth by side-flashing to other metal in the structure. There is therefore a risk of flashover from the protection system to any other metal on or in the structure. If such flashover occurs, part of the lightning current is discharged through internal installations, such as pipes and wiring, and therefore constitutes a risk to the occupants and the fabric of the structure.

There are two ways of preventing side-flashing namely:

a) Isolation
b) Bonding

Isolation requires large clearances between the lightning protection system and other metal in the structure. The main drawbacks to isolation lie in the difficulty in obtaining and maintaining the necessary safe clearances and in ensuring that isolated metal has no connection with the ground. In general, bonding is the more commonly used method.

3.3 Thermal effects

For the purposes of lightning protection, the thermal effect of a lightning discharge is confined to the temperature rise of the conductor through which the current passes. Although the current is high, its duration is short and the thermal effect on the protection system is usually negligible.

In general, the cross-sectional area of a lightning conductor is chosen primarily to satisfy the requirement for mechanical strength, which means that it is large enough to keep the rise in temperature.

3.4 Mechanical effects

Where a high current is discharged along parallel conductors in close proximity of along a single conductor with sharp bends, considerable mechanical forces are produced. Secure mechanical fittings are therefore essential.

4.0 COMPONENT PARTS

The principal components of lightning protection systems are as follows:

4.1 Air terminations

The primary function of air termination is to capture the lightning strike to a preferred point, so that the discharge current can be safely directed via the down conductor(s) to the grounding system.

The minimum dimension of lightning conductor to form the air termination is 20 x 2.5mm (50mmsq). Copper and aluminium are the recommended materials for installations required to have a long life. If there is any difficulty in the use of copper or aluminium, galvanized steel strip of the same cross-section as that recommended for copper may be used.

On a reinforced concrete structure, the air termination should be connected to the reinforcing bars in the number of positions needed for down conductors.

For buildings where the roof forms part of the air termination network, the minimum thickness of metal used for roofing not less than those given in Table 1 below.

Material	Minimum thickness mm
Galvanized steel	0.5
Stainless steel	0.4
Copper	0.3
Aluminium and zinc	0.7
Lead	2.0
NOTE The figures in this table are based on contemporary building practice and will be satisfactory where the roof forms part of lightning protection system. However, damage by way of puncturing may occur with a direct arc-connected strike.	

Table 1: Minimum thickness of sheet metal used for roofing and Forming part of the air termination network.

4.2 Down conductors

The function of the down conductor is to provide a low impedance path from the air termination to the ground system so that the lightning current can be safely conducted to earth, without the development of excessively large voltages. In order to reduce the possibility of dangerous sparking (side-flashing), the down conductor route(s) should be as direct as possible with no sharp bends or stress points where the inductance, and hence impedance, is increased under impulse conditions.

The position and spacing of down conductors on large structures is often governed by architectural convenience. However, there should be one down conductor for each 20m or part thereof of the perimeter at roof level or ground level, whichever is the greater. Structures over 20m high should have one per 10m or part thereof.

4.3 Joints and Bonds

Any joint other than one of welded type represents a discontinuity in the current conducting system and is susceptible to variation and failure. Accordingly, the lightning protection system should have as few joints as possible. Therefore, joints should be mechanically and electrically effective, e.g. clamped, screwed, and bolted, riveted or welded. With overlapping joints, the overlap should be not less than 20mm for all types of conductors.

Bonds are used to join a variety of metallic parts of different shapes and compositions and cannot therefore be of standard form. Because of their varied use and the risk of corrosion, careful attention needs to be given to the metals involved, i.e. that of the bond and of the items being bonded.

4.4 Test joints.

Each down conductor should be provided with a test joint in such a position that, whilst not inviting unauthorized interference, it is convenient for tests. Plates indicating the position, number and type of earth electrodes should be fitted above each test point.

4.5 Earth termination

When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous over voltages, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 ohm when measured at low frequency) is recommended.

Based on British Standard BS 6651:1999, the whole of the earth termination network should have a combined resistance to earth not exceeding 10ohms without taking account of any bonding to other services. If the value obtained for the whole of the lightning protection system exceeds 10 ohms, a reduction can be achieved by extending or adding to the electrodes or by interconnecting the individual earth electrodes of the down conductors by a conductor installed at least 0.6m below the ground, sometimes referred to as a ring earth electrode.

From the viewpoint of lightning protection, a single integrated structure earth-termination system is preferable an is suitable for all purposes (i.e. lightning protection, power systems and telecommunication systems).

4.6 Earth electrodes

Earth electrodes should consist of metal rods, tubes or strips or a combination of these. Interconnected reinforcing steel in concrete foundations or other suitable underground metal structures should preferably be used as an earth electrode. When metallic reinforcement in concrete is used as an earth electrode, special care shall be exercised at the interconnections to prevent mechanical splitting of the concrete.

5. MANAGEMENT OF THE LIGHTNING PROTECTION SYSTEM

A good engineering practice in any system to be selected has to carefully include the Risk Assessment analysis based on lightning localized parameter, level of protection required, type of structures to be protected, area of coverage, bonding selection to the other system, organized supervision during installation, monitoring for system performance and maintenance aspect of the system during the operation.

5.1 Direct Strike Protection System

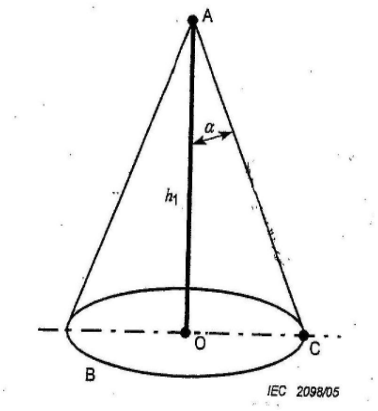
'Zone of protection' is the volume within which a lightning conductor gives protection against a direct lightning strike by directing the strike to it. For the design of the air-termination system, the following methods should be used, independently or in any combination, providing that the zones of protection afforded by different parts of the air-termination overlap and ensure that structure is entirely protected.

i) protective angle method;
ii) rolling sphere method;
iii) Mesh method.

i) **Protective angle method**

Air termination conductors, rods, masts and wires should be positioned so that all parts of the structure to be protected are inside the envelope surface generated by projecting points on the air-termination conductors to the reference plane, at a protective angle to the vertical in all directions.

Figure 1 below shows the volume protected by a vertical rod is assumed to have the shape of a right circular cone with the vertex placed on the air-termination axis.



Key

A	tip of an air-termination rod
B	reference plane
OC	radius of protected area
*h*1	height of an air-termination rod above the reference plane of the area to be protected.
α	protective angle

For structures not exceeding 20m in height, the angle between the side of the cone and the vertical at the apex of the cone is known as the protective angle. For the practical purpose of providing an acceptable degree of protection for an ordinary structure up to 20m high and up to a height of 20m for a higher structure, the protective angle of any single component part of an air termination network, namely either one vertical or one horizontal conductor, is considered to be 45°. Between two or more vertical conductors, spaced at a distance not exceeding twice their height, the equivalent protective angle may, as an exception, be taken as 60° to the vertical.

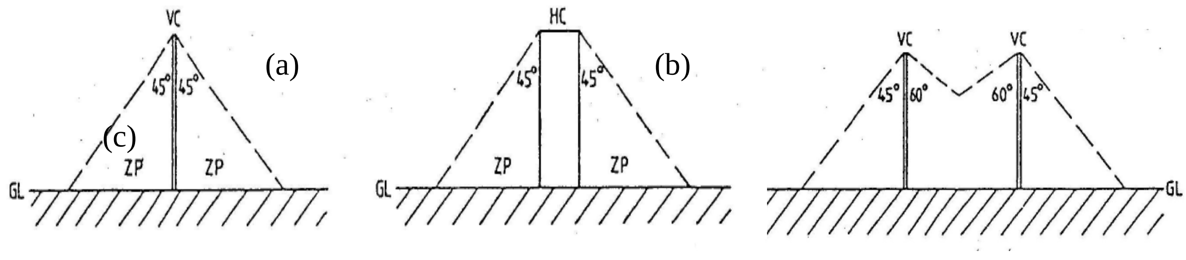


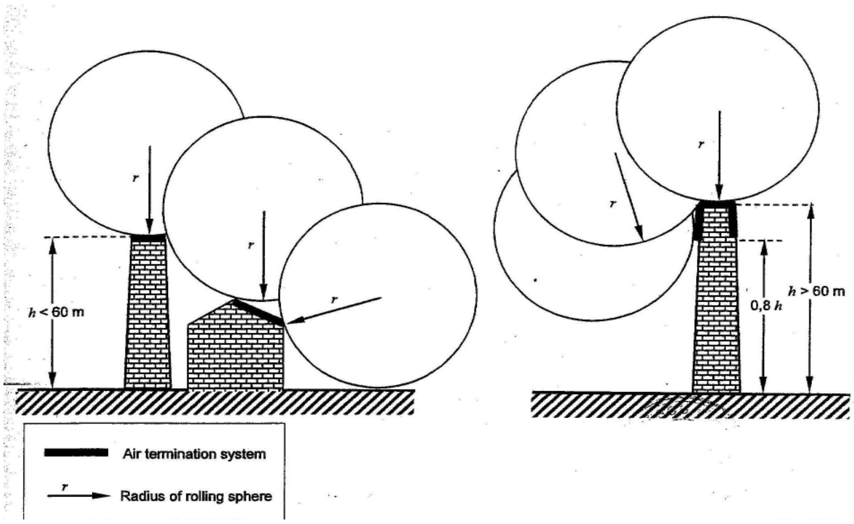
Figure 2: Protective angles and zone of protection for various forms of air termination

ii) Rolling Sphere method

Rolling sphere method may be used to identify non-protected parts of tall, complex structures. For structures exceeding 20m in height, the protective angle of any conductors up to the height of 20m would be similar to that for lower structures. However, if there is a possibility of such buildings being struck on the side, it is recommended that the protected volume is determined using rolling sphere method.

On all structures higher than the rolling sphere radius r, flashes to the side of structure may occur. Each lateral point of the structure touched by the rolling sphere is a possible point of strike. However, the probability for flashes to the sides is generally negligible for structures lower than 60m.

In general, the smaller the size of the sphere, the greater the protection but the more costly the installation. Sizes from 20m to 60m have been recommended but BS 6651 recommended that calculations should normally be based on a sphere of radius 60m. However, a sphere of radius 20m should be used for buildings with explosive or highly flammable contents or which contain sensitive electronic equipment.



iii) Mesh method

Method used for protecting large area of flat roof whereby the network of the air-termination is recommended to be in the form of a grid to reduce the effect of flashover caused by large induction loops.

Air termination networks may consist of vertical or horizontal conductors or combination of both. No part of the roof should be more than 5m from the nearest horizontal conductor except an additional 1 m may be allowed for each metre by which the part to be protected is below the nearest conductor. For large flat roofs, this is achieved typically by use of an air termination network mesh of approximately 10m x 20m. Various forms of air termination are given in Figure 3 & 4.

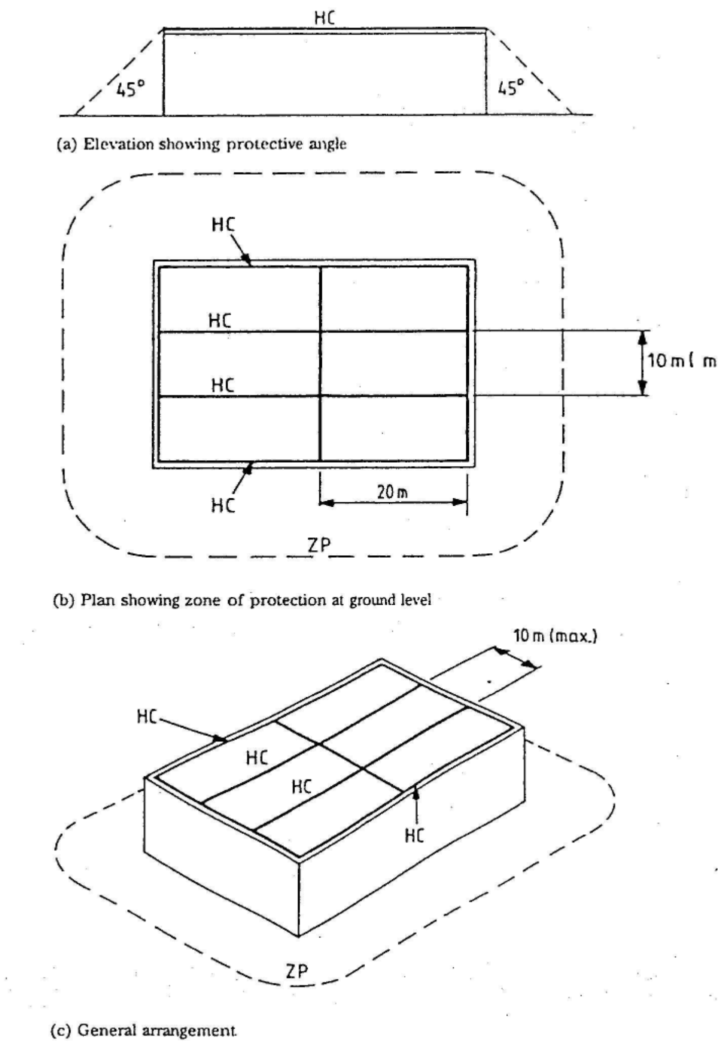


Figure 3: Air termination for a flat roof

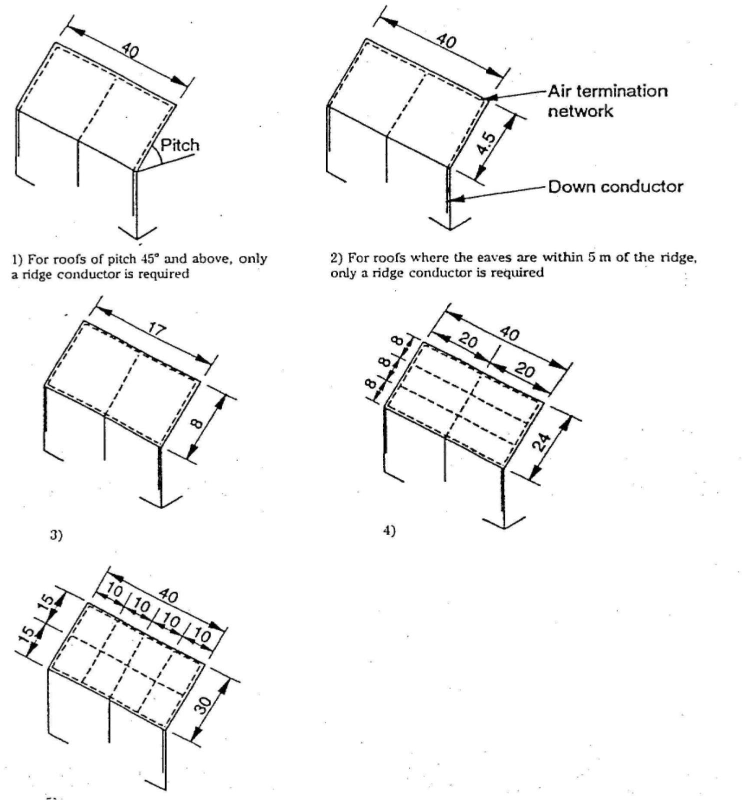


Figure 4: Air terminations and concealed conductors for buildings less than 20m high with high sloping roofs

These are examples of air terminations for various sizes of roof, but the criteria to be met when designing the roof network are:

- no part of the roof should be greater than 5 m from the nearest conductor.
- a 20 m x 10 m mesh should be maintained.

5.2 Transient Over voltage (Electronic Systems) Protection

When lightning strikes a building, transients are generated on adjacent power, data, telephone and/or RF lines. As these transients pass through electronic equipment on their way to earth, they can cause both immediate damage or longer term component degradation.

Today our electronic systems are intrinsically connected to the outside world; not only by mains power cables, but also through data and telephone lines, RF feeders, etc. Transient over voltages from lightning activity up to 1 km away can destroy electronic equipment inside a building, even when the building itself has not been struck.

Transient over voltages are large, very brief and potentially destructive increases in voltage. It can be caused by:

i) Resistive coupling: the most common cause of transient over voltages and it will affect both underground and overhead lines. Resistively coupled transients occur when a lightning strike raises the electrical potential of one or more of a group of electrically interconnected buildings (or structures). Common examples of electrical interconnections are :

- power feeds from substation to building or building to building.
- power supplies from the building to external lighting, CCTV or security equipment.
- telephone lines from the exchange to the building or between building telephone lines.
- between building LANs or data communication lines.
- Signal or power lines from a building to external or field based sensors.

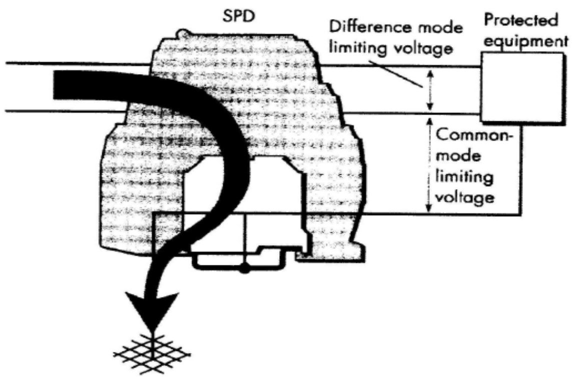
ii) Inductive coupling: is a magnetic field transformer effect between lightning and cables. A lightning discharge is an enormous current flow and whenever a current flows, an electromagnetic field is created around it. If power or data cabling passes through this magnetic field, then a voltage will be picked-up by, or induced onto it.

iii) Current injection from a direct strike: direct lightning strikes to installation wiring or exposed electrical systems such as sensor heads or aerials may inject sufficient current into the wires to cause explosive vaporization. This can cause considerable physical damage to the installation wiring over a considerable length.

Owing to the very high voltages associated with direct injection, damage to other circuits is possible as a result of high voltage breakdown and flashover on the terminal blocks, plugs and sockets, etc. so injecting large currents or voltages into the other circuits and causing multiple failures in them.

Surge Protection Devices (SPD) and Location Categories

Surge Protection Devices limit the transient voltage to a level which is safe for the equipment they protect by conducting the large surge current safely to ground through the earth conductor system. Current flows past, rather than through, the protected equipment and the SPD thereby diverts the surge.



Path of surge diversion through a Surge Protective Device

The SPD limits both common and difference mode voltages to the equipment. The voltage which the equipment receives during a surge is called the 'limiting' or 'let-through' voltage.

Let-Through Voltage

The larger the transient voltage reaching the electronic equipment, the greater the risk of interference, physical damage hence system downtime. Therefore, the transient over voltage let through the protector should be as low as possible as and certainly lower than the level at which interference or component degradation may occur.

Thus, a good surge protection device must have a low let-through voltage between every pair of conductors. More importantly, since lightning is a multiple event, the surge protection device must be able to withstand repeated transient over voltages.

Let-through voltage should be quoted for a relevant standard test.

Mode of Protection

A transient over voltages can exist between any pair of conductors:

- Phase to neutral, phase to earth and neutral to earth on mains power supplies.
- Line to line and line(s) to earth on data communication, signal and telephone lines.

Thus, the transient over voltage protection devices should have a low let-through voltage for all combinations of conductors as shown in Figure below.

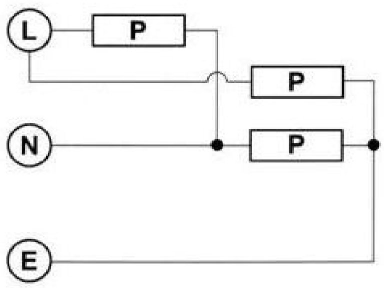


FIGURE 1 - Modes of protection (P) for single phase mains power supply

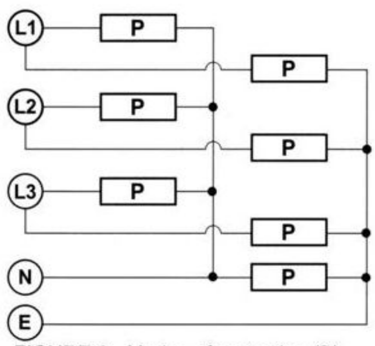


FIGURE 2 - Modes of protection (P) for three phase mains power supply

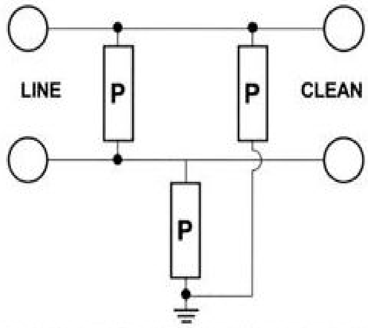


FIGURE 3 - Modes of protection (P) for data communication, signal or telephone lines.
Note: Data line protectors usually include some line impedance, which is omitted from the above for clarity.

Three categories of protection are addressed in mains power, and their locations are as follows:

- Location Category C

  Surge protection devices installed in the following locations fall into category C.

  i) on the supply side of incoming power distribution boards/switchgear (i.e. boards that bring power into a building, from the supply authority, HV/LV transformer or another building)
  ii) on the load side of outgoing power distribution boards/switchgear (i.e. boards that take power to other buildings, external lights, pumps etc.);
  iii) on the outside of a building.

- Location Category B

  Protection devices installed in the following locations fall into category B:

  i) on a power distribution system, between the load side of the incoming mains power distribution board/switchgear and supply side of a socket outlet/fused connection unit;
  ii) within apparatus that is not fed via a socket outlet/fused connection unit;
  iii) load side of socket outlets/fused connection units located less than a 20m cable run from category C.

- Location Category A

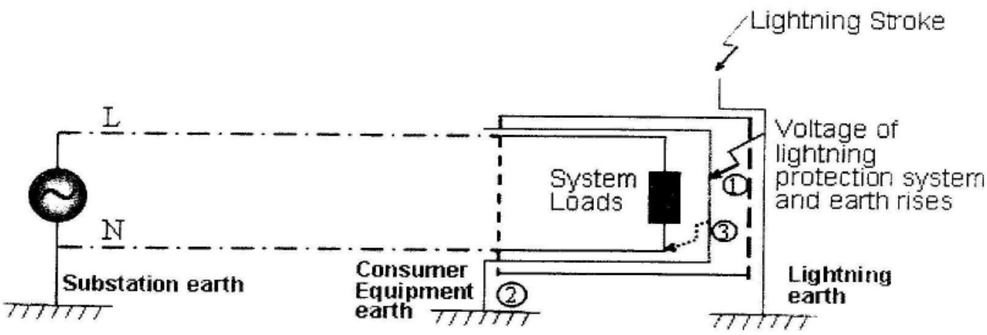
  Protection devices installed on the load side of socket outlets/fused connection units and more than a 20m cable run from category C, fall into category A. Category A does not appear in small buildings where socket outlets are all less than 20m from category C.

Within a given location category, the severity levels of the transients encountered will increase as risk of transients occurring increases. This can be represented by the system exposure level, which in turn can be derived from the Risk Assessment.

6.0 Earthing System

6.1 Connection of Lightning & Earthing System

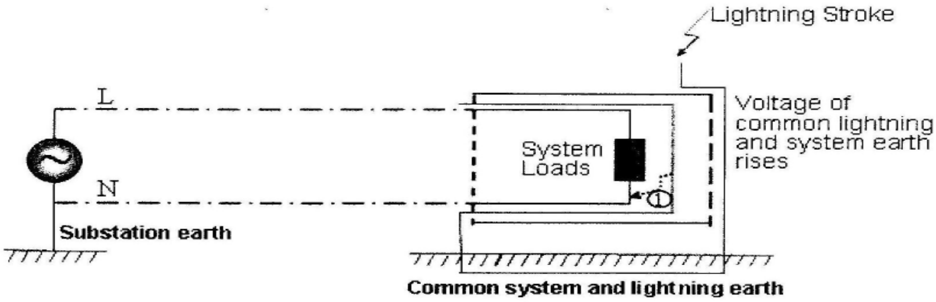
A. Separate Lightning & System Earths



(1) Strong likelihood of flashover to unbounded equipment connected to system earth as there exists potential differences.

(2) Voltage at system earth will still rise, due to close proximity of lightning and system earth, but perhaps to a smaller value as compared to case when the earths are common. Therefore, the probability of flashover to line and neutral (3) of power supply line is not eliminated.

B. Common Lightning & System Earths



(1) Likelihood of flashover to line and neutral of power supply line when voltage on earth system (i.e. lightning protection & system earth) rises – as the neutral is remotely earthed at the Utility substation.

Advantages:

- Little likelihood of side flashes to earthed objects/appliances in the premises.
- A much lower overall earthing resistance.

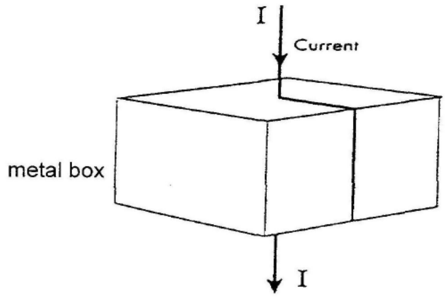
6.2 Coordination of Earthing Systems

It is POTENTIAL DIFFERENCES set up between and in systems which cause propagation of surge voltages.

- Direct lightning strikes to structures housing equipment systems will cause potential rises and hence potential differences.
- Entry of lightning currents into the earth will cause Ground Potential Rises (GPR) and hence Ground Potential Differences (GPD).

To reduce / eliminate GPD, we implement POTENTIAL EQUALIZATION. This can be achieved by:

- A closed metal box or Faraday cage
- A zero Potential reference grid (ZPRG)
- Bonding between various earth systems.

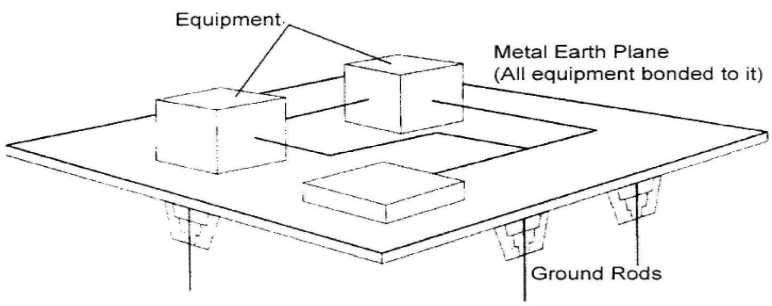


A metal box used as a Faraday cage

6.3 The Ideal Earthing System

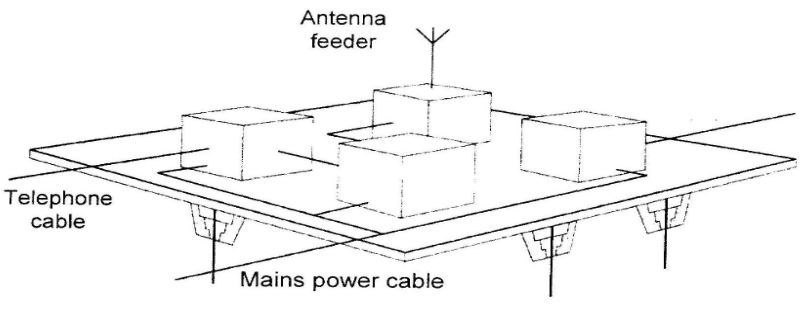
Salient points / requirements of the ideal system which virtually eliminates problems with surges (next best thing to a closed metal box) are:

a) All equipment is metal-cased
b) All equipment sits directly on a metal sheet to which it is electrically bonded. Everything shares the same low-impedance zero volt reference.
c) For good measure, the metal 'earth plane' is at ground level and connected to ground by a system of rods driven into the soil so that it is at local ground potential.
d) There is no connection to other electronic systems.
e) The system is physically small; a few square metres at most, so making the likelihood of a direct strike negligible.



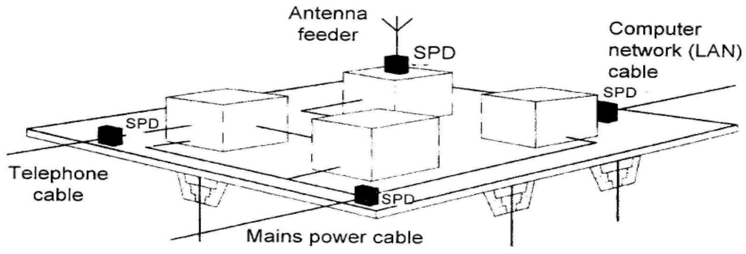
The perfect earth – sitting on a metal earth plane

However, real systems inevitably have cables connected to its systems from the 'external world' making a less than ideal system. The connected cables can be mains power, telephone, telemetry, antennas, computer networks, external lighting power cables, etc. Voltage surges can be transmitted to and from the equipment via these cables by potential differences generated.



A less than ideal system – with connections to the external world

Therefore, SPDs are required to limit both COMMON and DIFFERENTIAL mode voltages to the equipment.



Requirement of surge protective devices (SPDs)