Application Note
(0015-D74V3)

EARTHING AND BONDING FOR SURGE PROTECTION

Novaris Pty Ltd
72 Browns Road Kingston
PO Box 2010 Kingston
Tasmania 7050 Australia

+61 3 6229 7233
sales@novaris.com.au
www.novaris.com.au

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1 LIGHTNING – THE NEED FOR SURGE PROTECTION

1.1 EARTH – a simple definition

In this Application Note, *'earth'* is defined as the zero-volt reference for an electrical/electronic system.

Note 1 : There is no such thing as *'true earth'*, i.e., a universal *'zero-volt reference'*.
Note 2 : In this application note, the term *'ground'* is applied to the surface of the planet, i.e., soil and rock. As with most terminology, what is referred to as *'earth'* in Australia and Asia may be referred to as 'ground' in North America and vice-versa.
Note 3 : Many electrical systems need a connection to the ground. Main's power is an example. Lightning is an interaction between the atmosphere and the ground, these systems usually need protection.
Note 4 : Self-contained electronic products such as battery powered devices, radios, battery tools, calculators etc. are isolated from ground and for them, therefore, the issue of earthing is irrelevant.

1.2 EARTH – Simple definition

Earthing problems can seem complex at first sight – but this need not be the case provided two basic questions are borne in mind at each stage: –

a) When an SPD operates, where will current flow?
b) What voltage *(or 'potential difference')* will develop when it does?

Answering these questions is the object of much of this document. Remember also that: –

c) Lightning-induced current will ultimately flow to earth, i.e., into the mass of the earth *(ground).*
d) When tackling a new installation, a diagram or sketch is usually valuable.
e) Australian standard AS 1768 is very practical and helpful in this regard.

1.3 Complete protection – Faraday cage

If the entire electronic system can be enclosed in an electrically conducting *(e.g.,'metallic')* box, unwanted currents flowing round the outside of the box will not generate any potentials inside *(see figure 1).* This is the principle of the so-called *'Faraday cage'*. Electronic equipment inside such a box will survive even a direct strike.

Although at first sight this concept may seem trivial, in aviation it is very important. Aircraft designers strive to make airframes as close to *'closed metal boxes'* as possible. In regular service, passenger aircraft expect to be struck by lightning at least once a year on average. A great deal of modelling and testing is undertaken to make sure avionic equipment survives lightning strikes unscathed.

Practical tip – the shielding effect of a metallic enclosure means it is safer to remain within a metal-bodied car during a thunderstorm than to leave it.

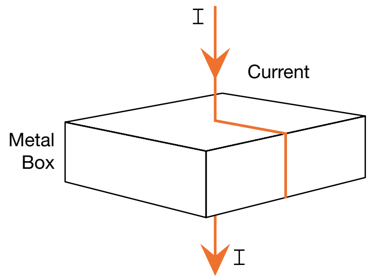

Figure 1 A metallic box as a Faraday cage

1.4 An idealised earthing system – next best thing to a Faraday cage

When dealing with a real-life lightning protection problem, it is helpful to keep an *'ideal next best thing to a metallic box'* solution in mind, in order to reach the closest practical approximation to this.

This *'ideal'* system, which virtually eliminates problems with surges – is shown in figure 2. Important points 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 common 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 are no connections to other electronic systems
e) The system is physically small, a few square metres at most, so making the likelihood of a direct strike low.

The purpose of the metal *'earth plane'* sheet is to provide a low impedance to any induced currents which flow, resulting in very small induced voltages. Such an area of zero or minimal potential differences is often referred to as an *'equipotential zone'.*

It is worth explaining what is meant by *'low impedance'*. This subject is covered in detail in section 4. However in short, with lightning-induced surges, currents exceeding 10,000 amps may be involved, developing a potential difference of 1 kilovolt across each ohm of impedance for each kiloamp of current which flows.

The lowest impedance is provided by a sheet of *'high-conductivity'* metal – Aluminium is ideal for this application in that it is readily available, can be protected from corrosion and is easily worked and machined.

For a 50-60Hz electrical supply, the purpose of the protective earth conductor is to provide a *'low impedance'* to supply frequency fault currents, so that voltages developed across a length of cable are insufficient to cause a serious electric shock to any people within the installation. Metal plumbing and heating pipes are bonded to the protective earth conductor system to create a safe equipotential zone. However, as we shall see, this system, though adequate at the supply frequency, cannot be considered a low impedance equipotential zone for lightning-induced transients. See section 3 for details of why this is the case.

1.5 A less than 'ideal' system

We still have our excellent grounded earth plane, but, as in figure 3, our equipotential zone is now breached by cables coming in from outside. These could be for: –

a) Mains or other power
b) Telephone
c) Telemetry
d) Antennas
e) Computer network
f) External lighting power cables

Now that we have a system of cables, we do need to worry about lightning- induced transients and it is time to evaluate in more detail *(see section 3)* the way in which cables can pass transients to our equipment and the means by which surge protection devices operate.

1.6 Summary - the threat from lightning

a) Lightning strikes to ground involve large currents *(averaging tens of kiloamps (kA).*
b) Because the ground *(i.e., soil and rock)* is not a perfect conductor, lightning current flowing through the ground resistance develops very large voltages *(hundreds of kilovolt (kV) or more)* between points on the Earth's surface.

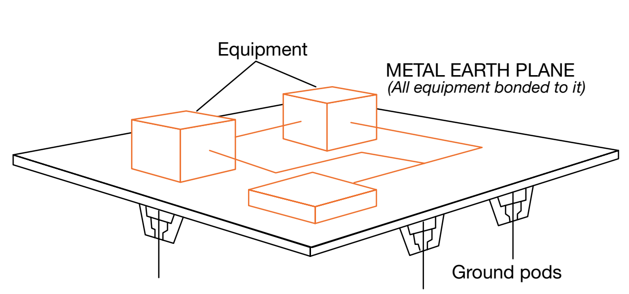

Figure 2 The *'perfect'* earth!

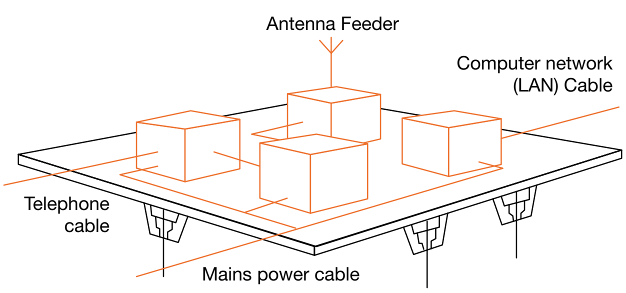

Figure 3 A less than *'ideal'* system

c) Such points could be two buildings containing electrical installations and linked by cables; a strike close to one *(say within 1km)* raises the potential of the ground and a large potential difference develops between the two installations.
d) A surge has been created; if current flows *(as it will when there is an enormous potential difference between the two installations),* the resulting damaging current path is between the ground connections of the two installations.

2 SURGES AND SURGE PROTECTION

2.1 Common and difference mode surges

Cables consist of more than one conductor. During a surge, all conductors will tend to move together in potential relative to local ground. This is referred to as common mode *(figure 4).*

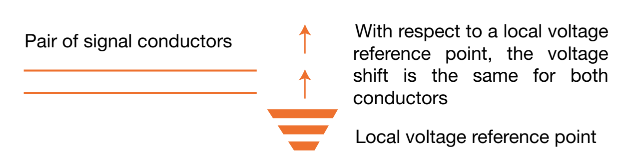

Figure 4 Common mode voltage

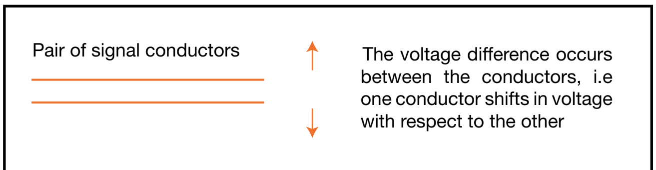

Figure 5 Differential mode voltage

However, a difference in voltage can also develop between the conductors. This is referred to as *'differential mode' (also known as 'transverse' mode) – (figure 5).*

Both can damage equipment. Common mode surges are usually larger, but equipment tends to be more vulnerable to differential mode. However, almost all Novaris protectors limit both types of surges.

2.2 How surges damage equipment

Before a surge can damage electronic equipment, several conditions need to be present: –

2.2.1 Voltage/current relationship

Sufficient voltage must be present between two susceptible points on the equipment to cause a current to flow. The vulnerable points are usually signal or power supply inputs or outputs, and the equipment's zero voltage reference point which is commonly the casing or chassis connected to the mains supply earth. The voltage above which damaging current starts to flow is often called the breakdown voltage *(or potential).*

2.2.2 Time/energy relationship

The current must flow for sufficient time to deposit enough energy within electronic components to cause damage. However some components such as capacitors can be damaged immediately the current starts to flow as the leading voltage edge actually punches a hole through the insulation elements, the dielectric in this case.

2.3 Surge protection devices (SPDs) – how they work

Surge protection devices *(see the glossary – Appendix C for other commonly-used terms for these)* 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 *(see figure 6).*

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

One way of regarding a surge protection device is as an earth connection *(figure 7)* which is only present during a surge.

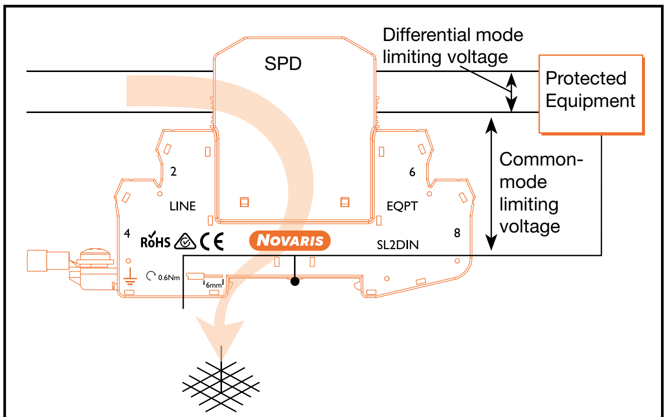

Figure 6 Path of surge diversion through an SPD

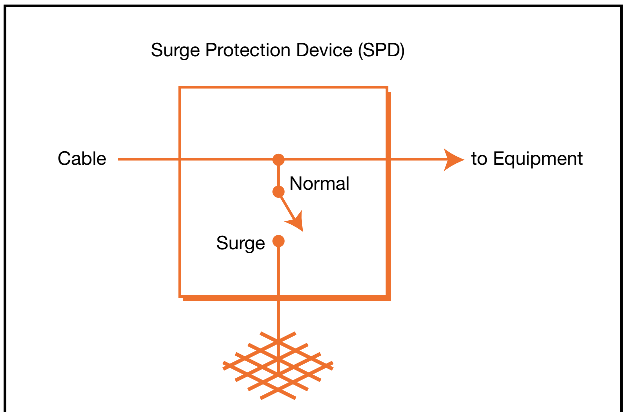

Figure 7 SPD acting as an earth connection

2.4 What equipment needs protecting?

In principle, wherever a cable enters an equipotential zone, equipment connected to that cable is exposed to possibly damaging surges. The degree of risk depends on factors such as: –

a) Cable length.
b) Frequency of occurrence of lightning.
c) Exposure of the site to lightning and the degree of isolation.
d) Whether cables run above ground or underground.
   It is essential to protect ALL cables which introduce a significant risk, as will be detailed later.

Consider again our system on its earth plane, but now with all incoming cables *(figure 8)* feeding equipment through suitable SPDs. Because of the low impedance earth plane, this will still be close to an ideal system.

Note 1 : Small, self-contained, isolated pieces of equipment, e.g., multimeters, transistor radios and music players, do not, in general, need protecting, because they do not have a ground connection.
Note 2 : AS1768 provides sound and practical guidance on the factors affecting the placement and selection of SPD's for all applications.

2.5 Case study – telephones, FAX machines and modems

This case study illustrates points made in the previous sections in part 3. While it is based on Australian practice, the points it makes have a general application.

For decades until quite recently, the only communication device in the home was the telephone, connected to the public switched telephone network *(PSTN) by* a wire-pair. A telephone was powered from the network and had no electrical connection to the house. Being electrically isolated, it was therefore not vulnerable *(apart from rare direct strikes to the house)* to common mode transients on the telephone wires. Protection from differential mode transients was given by a gas-discharge tube *(GDT)* fitted in the house incoming line-box. Although the limiting voltage of the GDT can be several hundred volts for the first microsecond or so of the transient, this was generally adequate – difference mode voltages of up to 180V or so can occur during normal operation.

Next came FAX machines and, more recently, DSL/VDSL modems linking personal computers to the Internet through the telephone connection. These are usually powered from the house electrical mains. They are isolated up to a point by the primary to secondary insulation in the power supply transformer,however, a lightning transient can create a common mode voltage sufficient to break down this insulation and damage the circuit components. A current path is created between the telephone line and the mains supply, and damage to the FAX machine or modem is the result.

Note that even though double insulation is normally used, with no direct connection to the mains protective earth conductor, this is of little consequence when a transient voltage of several kilovolt occurs. In any case, neutral and earth conductors are bonded at some point on the supply *(in Australian installations at the point where the mains supply enters the building, MEN system).*

To recap, damage is caused by the presence of a voltage difference between the telephone wires and local earth, in this case the electrical mains, which is sufficient to overcome the breakdown potentials of the power supply and the equipment. Current flows through the telephone line, equipment and power supply to the mains supply for sufficiently long to deposit enough energy within the components to cause damage. Ultimately, the current flows into the ground where the mains supply has its connection with the soil.

3 EARTHING FOR SURGE PROTECTION

3.1 *Introduction – earth impedance and its effects*

In reality, very few systems are bonded to an earth plane or mat. In most installations earthing is done with cables. Think of the two questions given at the beginning of this document:

a) When an SPD operates, where will the surge current flow?
b) What voltage *('potential difference')* will develop when it does?

The answer to these questions in any particular case depends on the position and impedance of the connection path to earth.

3.1.1 *Example*

The use of separate connections to ground, such as separate ground rods, can cause unwanted voltages to be developed across the ground impedance *(figure 9)*. These can be significant.

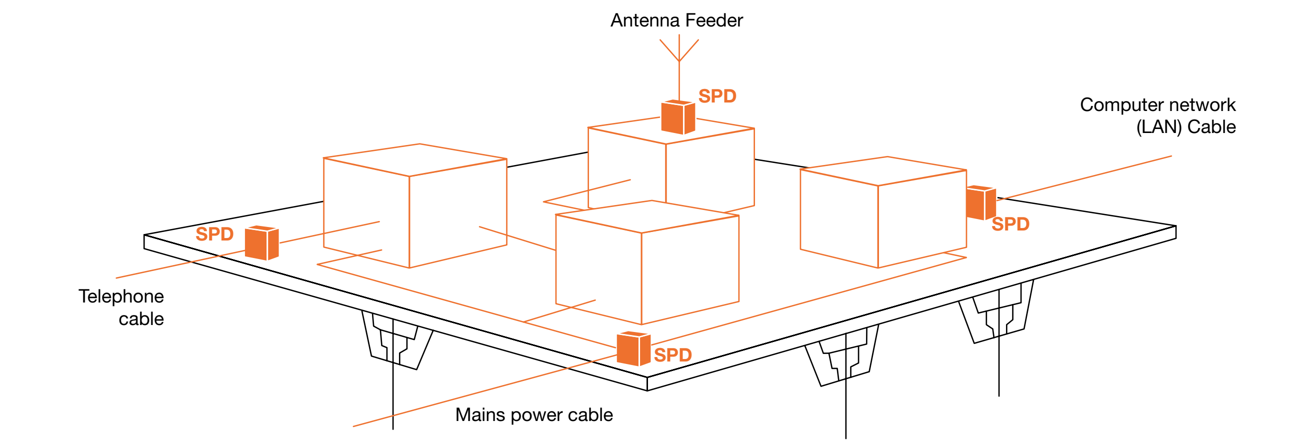

Figure 8 SPDs on incoming cables protecting connected equipment

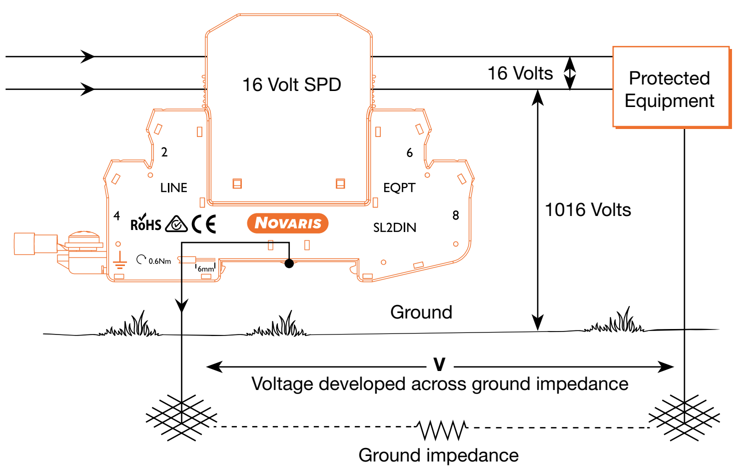

Figure 9 Voltage developed between separate ground connections

Assume an SPD with a limiting voltage of 16V is connected as shown in figure 9 and that the impedance from the body of the SPD to the equipment earth, via the ground, is 10Ω. Depending upon the soil and other circumstances, this can be a much higher value.

A 100A peak surge current flowing through the ground impedance will develop 1000V through the ground. The SPD will limit the voltage across itself to 16V and the equipment will be subjected to 1016V instead of the required 16V. Damage to the equipment is very likely. Fortunately, it is possible to improve on this as we shall see after studying *'impedance'* a little more closely.

4 EARTH IMPEDANCE

4.1 *Inductance and resistance*

Conductors possess resistance and inductance *[see reference 4]*. The effects of these *(figure 10)* are additive as they appear in series.

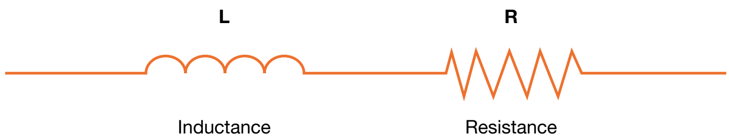

Figure 10 Resistance and inductance

The voltage drop along this cable is given by: –

$$\mathbf{V = IR + L}\ ^{dI}\!/_{dt}$$

where **V** = voltage, **I** = current,
R = resistance, **L** = inductance and
$^{dI}\!/_{dt}$ = rate of change of current.

For low frequencies, such as 50Hz mains supplies where Di/Dt is low, inductance is usually negligible in practice and only resistance needs be considered.
Resistance depends on the material used for the conductor. For any given material of uniform cross section, it is proportional to length and inversely proportional to the cross-sectional area, i.e.: –

$\mathbf{R} = \rho l/A$
where **R** = resistance in Ω, ρ = resistivity in Ω.m, l = length in m and **A** = cross sectional area *(m2)*.

For lightning surges, and even more so for electrostatic discharges *(ESD)*, which have extremely fast edges, inductance dominates. An earth which is adequate for the normal mains supply frequency, may not be so for surge protection. For typical surges inductance can produce 500 times more voltage drop than resistance. Always keep this in mind.

Inductance is more complicated than resistance. The formula for the inductance of a straight piece of wire is:

$\mathbf{L} = 0.2l\ \{\log_e 2.l/_r\ - 1\}\ \mu H$
where l = length and r = radius *(both in m)*

Note: In most cases, the wire will be much longer than it is thick, and its inductance decreases only slightly as the diameter increases. However, the inductance goes up even faster than the length, as table 1 shows. This is based on a peak surge current of 1kA, with a maximum rate of rise of 100A/µs, flowing through copper cable. This represents a relistic result that can happen in practice and isby no means an extreme case.

Table 1

Length (m)	Cross Section (mm²)	Resistance (Ω)	Inductance (µH)	Peak Resistive Voltage (V)	Peak Inductive Voltage (V)
1	1	0.017	1.4	17	144
1	2.5	0.0068	1.3	6.8	134
1	10	0.0017	1.2	1.7	120
10	1	0.17	19	170	1895
10	2.5	0.068	18	68	1803
10	10	0.017	16.6	17	1664

Note: The peak resistive and inductive voltages are not added together to give a total voltage, because they do not occur at the same time. The resistive voltage peaks with the current. However, the inductive voltage peaks when the rate of rise of current is at its maximum. At the peak of the current waveform, the rate of rise of current (by definition) is zero and therefore so is the inductive voltage.

A number of important points emerge from table 1: –

a) The inductive voltage dwarfs the resistive voltage.
b) Resistance is proportional to length; but inductance grows at a somewhat faster rate (*e.g., a 10m wire has more than 10 times the inductance of a 1m wire).*
c) Wire diameter has a relatively small effect on the inductance. For instance, increasing wire size from 2.5 to 10mm² *(quadrupling the area)* reduces inductance by less than 10%. The larger cable is much more difficult to bend, strip and install. However, if the mechanical strength of a larger cable is needed, use it.

In conclusion – keep all earth cables to SPD's as short and straight as possible!

Novaris recommends a minimum cable of 4.0mm² cross-section for any SPD earths. This is large enough not to overheat or melt during any likely surge *(and is unlikely to be the weak link in any case),* yet it is convenient to handle and install. However, as noted elsewhere, mechanical strength or other circumstances may favour the use of thicker cables.

Note: As a *'rule of thumb',* for cables up to a few meters in length; at least 100V is developed per meter of surge earth cable, per kiloamp of lightning- induced surge current; i.e., 100V/m/kA. This is based on a rate of rise of current of 100A/µs. Calculation based on a 1m length of 2.5mm² cable and the *'8/20µs'* current pulse test waveform *(see section 5.4)* gives 200V/kA.
Note: The inductive voltage transients are common-mode. Novaris surge protection devices have very low internal inductance values which means that transverse mode transients are limited effectively regardless of the earth cable length and size.

4.2 A note on 'skin depth'

High frequency current flowing through a conductor generates an electromagnetic field, one effect of which is to confine the current towards the outside of the conductor. This is known as the *'skin effect'* while the thickness of the layer to which most of the current is restricted is the *'skin depth'*. The higher the frequency, the smaller the depth. Consequently, because not all of the conductor's cross section is carrying its fair share of current, the resistance is higher than its direct current value.

For a copper conductor at 50Hz, skin depth is of the order of 10mm, so is seldom a problem. However, lightning transients induced on cables have considerably higher frequency components *(up to the order of tens of kHz)* in which case the skin depth – which is proportional to the square root of the inverse of the frequency – in copper is less than 1mm.

The skin effect will cause the resistive voltages to be greater than those shown in table 1. However, we believe this will less than double the resistive voltage. Since this is still dwarfed by inductance, the argument that length is more important than diameter holds good and, in fact, is reinforced. The skin effect simply means that some of the benefit of increasing the diameter of a conductor is lost.

4.3 Inductance and surge currents

Inductors store energy in the form of a magnetic field. If the voltage transient is large enough to cause surge current to flow in the equipment, this energy is released to cause damage. The energy (E) stored in an inductor of inductance L, is given by: –

$$E = L \cdot I^2/2$$

where I is the peak current.

If we again consider the case of 1kA peak current and the inductance of a 2.5mm² cable obtained from table 1, we find the results shown in table 2: –

Table 2

Length (m)	1	10
Inductance (μH)	1.3	18
Stored Energy (J)	0.65	9

The energy is ample to damage many electronic components. Semiconductor junctions, for example, can be damaged by energy of the order of microjoules *(1 microjoule [μJ] = 10^{-6}J).*

Note: An energy level of 1 joule (J) is approximately the energy needed to raise an average-sized apple 1m. If you catch an apple dropped from a height of 1m, the impact on your hand represents about 1J of energy.

Note: So far, we have assumed the wiring is straight. Bends in cables increase inductance: the reason why coils of wire are commonly used as *'inductors'*.

4.4 Surges on cables – some real measurements

This section describes results from measurements using standard test waveforms and the conclusions that can be drawn from these.

Surge testing is done using standard waveforms. The one shown in the oscilloscope trace shown in figure 13, which was used throughout these tests, is the so-called *'8/20'* waveform since it rises to peak current in 8μs, and falls to half the peak after 20μs.

To achieve the result shown in figure 11, a peak current of slightly more than 1kA was used. For reference, a copper sheet was placed across the surge generator terminals which were 10cm apart. A peak voltage of 5V was developed. Replacing the copper sheet with 10cm of 16 swg (standard wire gauge) wire produced 27V. The rest of the measurements were done using 1m long loops placed across the terminals.

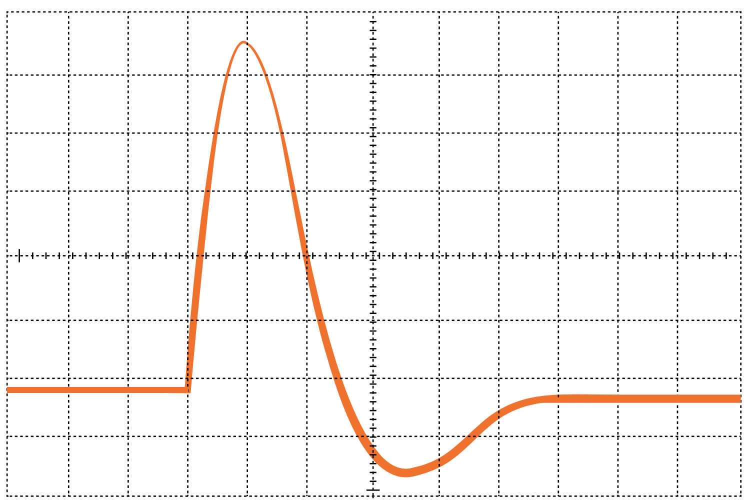

Figure 11 Plot of surge current waveform

Timebase = 5μs/division

Table 3

Conductor Type	Peak Inductive Transient Voltage (V)
2.5mm² cable	250
10mm² cable	200
10mm² '90A' braid	200
10-way ribbon cable*	170

Table 3 shows the voltage across three conductors 1m in length.
*Note: Each of the 10 conductors consists of 7 strands of 0.2mm diameter wire. Total conductor cross section = 2.2mm²

4.4 Surges on cables – some real measurements (cont)

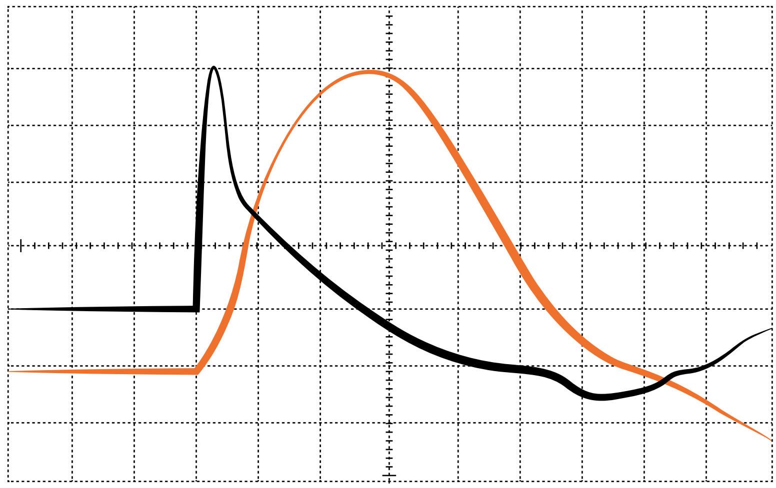

Figure 12 Plot showing inductive voltage and current waveforms Timebase = 1µs/division

Figure 12 illustrates the point made earlier about inductive voltage and current by reproducing an oscilloscope plot of the two waveforms. Table 4 shows the effect of electrically-paralleling 1m lengths of 2.5mm² cable, looped between the surge generator terminals.

Table 4

Conductor Type	Single cable	2 cables on similar paths	4 cables, similar paths	4 cables, differing paths
Peak Surge Voltage (V)	250	170	130	80

From these results, it can be concluded that two or more cables taking separate paths will provide a lower limiting voltage than a single large diameter cable. Even a small separation between the conductors improves matters considerably. The further apart the cables can be run without making them excessively lengthy, the less magnetic coupling there is between them and the lower the overall inductance.

4.5 Inductance – recap

a) Where possible, take advantage of available sheet metalwork, DIN rails have lower inductance than cables, use them as a priority.
b) For circular cross-section conductors, increasing the cable diameter gives a relatively poor improvement for the extra installation difficulty.
c) For a given cross-sectional area, flat conductors are better than round ones.
d) Running several cables electrically in parallel and physically spaced apart by several centimetres gives a worthwhile improvement.
e) A device which has many straight, flat, parallel conducting paths is called a *'metal sheet'* or *'panel'*!

5 EARTHING OF SPD's

5.1 The trouble with high impedance earth connections

Having considered the effects of inductance, we are in a better position to understand the consequences of having too much of it. Figure 13 illustrates an SPD connected between an incoming signal line, shown as a wire pair, and a piece of equipment. The SPD is connected to the equipment earth conductor *(typically the protective earth conductor)* which, in turn, is ultimately connected to ground. This gives a relatively long path.

The cables can be represented by their equivalent impedances – inductance in series with resistance – as shown in figure 14.

A common mode surge appearing on the cable indicates the presence of a transient voltage between the cable and the ground connection. The SPD operates and a rapidly increasing current starts to flow down the earth path. The voltage across the SPD is limited to its normal let-through voltage. However, due to the relatively high impedance of the earth path, a large voltage appears across it. The equipment sees this voltage plus the SPD let-through voltage – and the transient voltages can be added to the diagram *(figure 15)* while if there is a breakdown *(usually destructive)* within the equipment, another current path is generated *(figure 16)*.

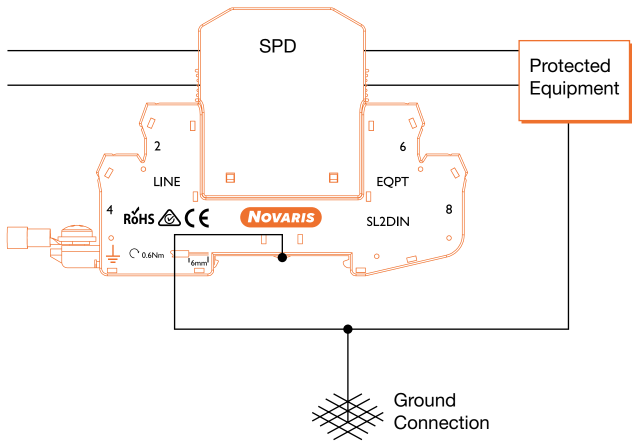

Figure 13 SPD connected to equipment earth conductor

5.1 The trouble with high impedance earth connections (cont)

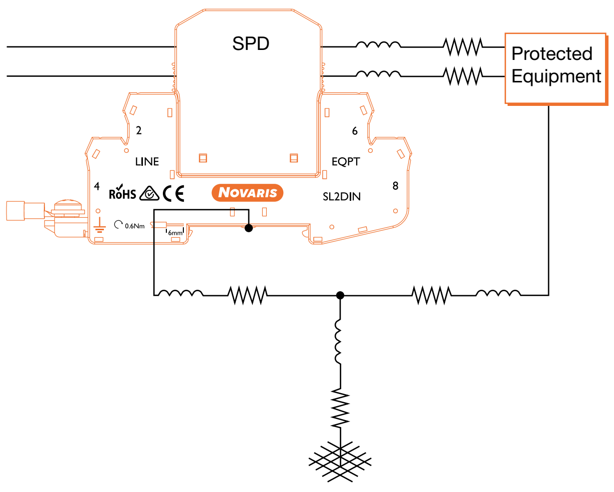

Figure 14 Cables shown as *'equivalent impedances'* between the SPD, protected equipment and earth

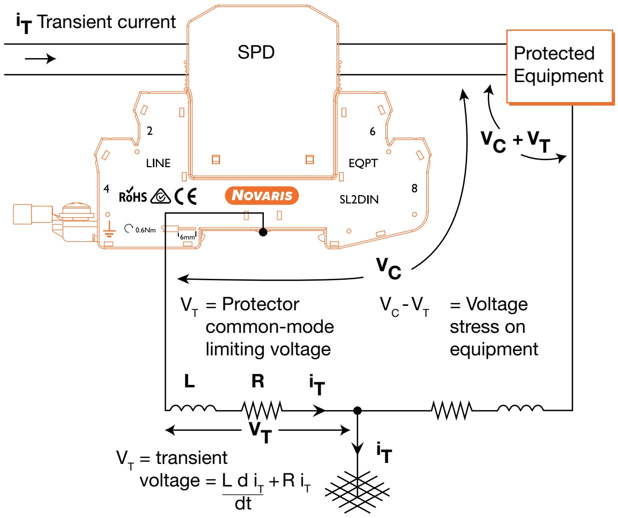

Figure 15 Relationship of earth surge currents to SPD limiting voltage

5.2 Re-positioning the earth connection to reduce the let-through voltage

The let-through voltage can be substantially lowered by re-positioning the earth connection. Locating the equipment earth *(i.e., its zero-volt reference)* at the SPD earth point produces the configuration shown in figure 17.

Figure 18 adds the currents and voltages to figure 17. The equipment is now subjected to an inductive voltage transient across the earth cable. There is still a large transient voltage developing between the ground point and the SPD, but this now doesn't appear across the equipment which receives only the let-through voltage of the SPD. In section 7 we will see how, in practice, an SPD can be positioned to satisfy the configuration depicted in figures 17 and 18.

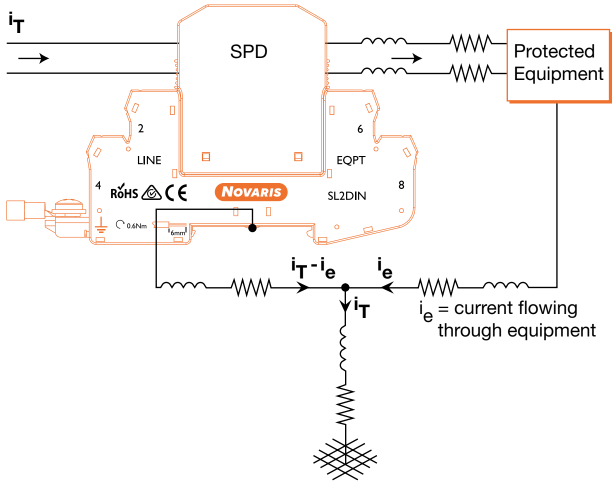

Figure 16 Voltage surges when a destructive breakdown occurs

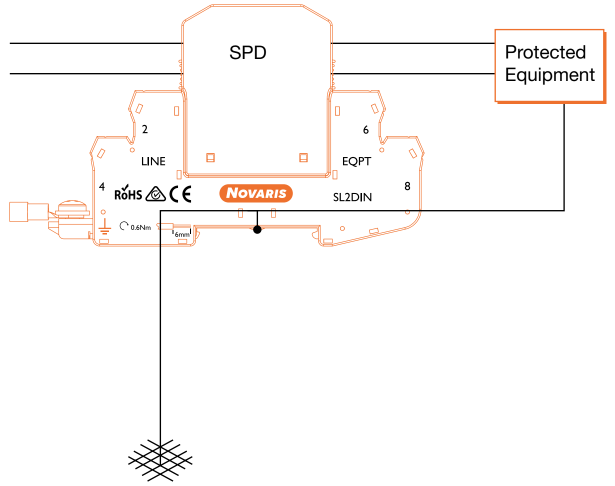

Figure 17 Locating the equipment earth at the SPD earth pointd

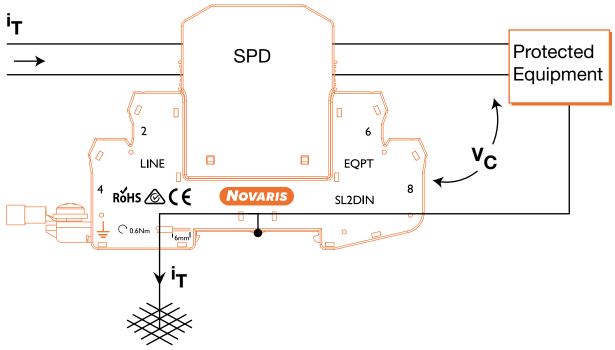

Figure 18 The effects of current and voltage when the equipment, earth is located at the SPD earth point

5.3 Using a bonding cable when the earth connection cannot be re-positioned

There are bound to be circumstances in which an SPD and the protected equipment are obliged to be some distance from the common earth point *(figure 19)*. If the SPD and equipment can be located close to each other, the limiting voltage can be reduced by bonding the two with as short a length of cable as possible This is known as an earth bond. Surge current is now shared between the SPD and equipment earths. The inductive transient voltage between them is reduced to that across the bonding cable.

Having emphasized the need to keep cables short to minimise inductance, with an Earth bond installed as in figure 19, it is apparent that it is an advantage for the equipment earth cable to have a high surge impedance relative to that of the SPD. Less surge current will then flow through the bonding cable and the overall let-through voltage will be lower.

Note: Resistance **MUST NOT** be added to the equipment earth as this can prejudice safety.

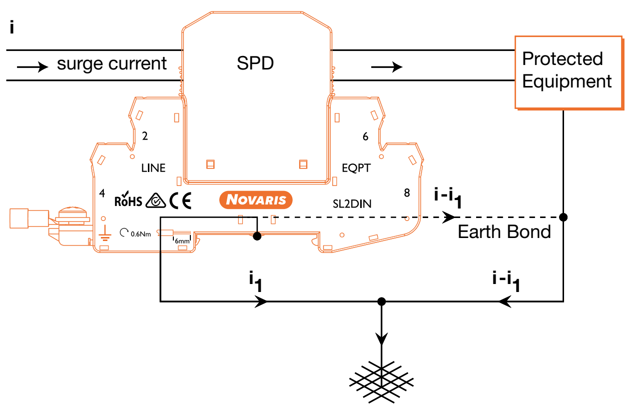

Figure 19 The use of an Earth bond

6 EARTHING SYSTEM CONFIGURATIONS AND INSTALLATION

6.1 Star-point earthing

A typical installation includes a number of items of equipment or devices, each with its own earth connection or chassis. If these are all connected to a common point, from which a cable runs to ground, the result is a star-point earth system *(figure 20).*

The individual devices are generally also linked by other cables but these have been omitted in figure 20 to avoid clutering the diagram.

Bearing in mind that the purpose of an earthing system is to keep all equipment within it at the same potential, we should now investigate what happens when current flows through the earth connection of just one device. The current i develops a voltage V across the impedance Z of its earth connection and this potential difference exists between this device and the others. Typically, a much larger voltage will be developed across the common ground connection but this does not affect the potential difference between the devices which can be thought of as moving together in potential.

The benefit of the star-point system is evident when compared to an earth system in which various devices are connected at various points along a common earth connection. This illustrates the *'worst-case'* condition in which the current flowing down the earth conductor leaves each device at a different potential.

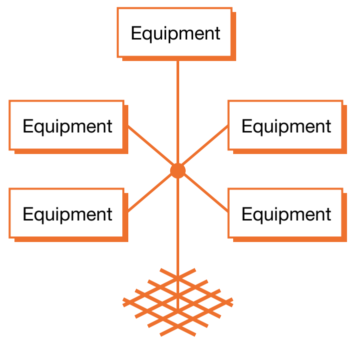

Figure 20 Star-point earth system

6.2 Implementing a star-point earthing system

6.2.1 Basic principles

In a typical installation, there will be a protective earth system such as that provided by the mains protective earth conductor. Ideally, interaction between the SPD earth and the protective earth should be minimised by star-pointing them together as detailed below.

First, find the point on the protective earth system which is electrically closest to ground. In a factory or office, this is likely to be the earth terminal of the main distribution board where connections are made to the incoming electricity supply. This provides the star-point to which all SPDs should be earthed, using connections which are as short and direct as possible. Surge currents can then flow to ground without flowing through the protective earth system within the building. As we have seen, these currents will generate a voltage between the earth terminal and the connection into the ground. The whole earthing system will rise in potential relative to the ground connection but minimal potential differences will be generated between devices within the installation.

Fitting SPDs for various devices at the main earthing location does call for all affected signal lines to be run close to this point, this is known as the *"point of entry"* and in many cases, especially if SPD's are being retrofitted, it is not practical or economic.

6.2.2 Star-point system installation – summary

- Locate the point on the protective earth system within the installation which is electrically closest to ground (*e.g., the earth terminal on the main distribution board)* – this will be the star-point connection between SPD earths and the supply protective earth.
- Route all signal cables to run as close to this point as possible.
- Fit SPDs on all signal lines as close to the star-point as possible.
- Connect the SPD earths to the star-point using connections which are as short and direct as possible.

6.2.3 *Practical connections*

If possible, make use of system metalwork, such as may be present at the main distribution board and mount the SPDs on metal panels to minimise the inductance of their earth connections, taking care that any paint or grease is first removed. Many Novaris SPD's are designed for earthing via the DIN mounting rail, use this method of earthing if possible, the DIN rail has a lower impedance than cables.

6.3 *SPD earths and protective earths*

Having introduced connections between surge protection devices and the mains supply system of the particular building, it is advisable to review what these are for.

6.3.1 *Surge protection earths*

The purpose of the surge protection earth is to carry transient currents to ground by as direct and low-impedance a path as possible – to minimise common-mode let-through voltage and to provide the best equipment protection. For this Novaris recommend the use of the DIN mounting rails or if this is not possible then 4.0mm^2 minimum cross-section cable where necessary *(i.e., where other metal panels cannot be used).*

6.3.2 *Mains protective earths*

The purpose of a mains protective earth conductor is to carry supply frequency fault currents for long enough to allow current-limiting devices such as fuses and circuit-breakers to operate. The size of this conductor is determined by its ability to carry the electricity supply fault currents. The *'fault current'* is the current which the circuit can deliver into a short-circuit.

6.3.3 *Other aspects*

If, for any reason, a conductor is used for both purposes, it **MUST**, at all costs, be capable of carrying the supply fault current and sized accordingly – remember, **SAFETY FIRST!**

In some circumstances, the surge and protective earth conductors are in parallel. Provided there is always an adequate protective earth conductor and good surge earthing practice is followed, it does not matter if surge and fault currents are shared between the two paths.

To make sure the correct size and type of mains protective earth conductors are used, consult the appropriate regulations. In Australia this is AS3000, known as the wiring rules.

6.4 *Surge protection for external connections*

Manufacturers of surge protection devices *(including Novaris)* recommend fitting SPDs to each cable which enters an installation from outside the building, why is this, is this simply a ploy to sell more products?

The answer is NO, for two reasons: –

a) Each cable provides an opportunity for surges to enter the building.
b) Failure to protect all cables may allow a surge on one to couple to another.

6.4.1 *Surge entering a building*

To illustrate the first point a), consider a device with two cables, both of which come from points remote from the installation and only one of which is fitted with an SPD. If, during a thunderstorm, there is a lightning strike to ground near the remote end of the unprotected cable, the device will suffer from a surge on the unprotected line. Breakdown *(probably destructive)* occurs and current flows to ground, either through the device or through its *'protected'* port and the output side of the SPD. In the latter case, both the device and the SPD may be damaged.

6.4.2 *Surge coupling from one cable to another*

For surge coupling, consider the simple system which depicts a signal cable and an item of mains-powered equipment.

During a surge, the SPD on the signal line operates correctly and transient current flows to ground through the earth conductor. However, the inductive voltage across the earth conductor appears between the other mains supply conductors. The neutral-earth voltage depends on the distance to the bond between them. If the SPD is at the main earth terminal of the distribution board, where the neutral-earth bond is situated, there will be little or no neutral earth transient and the inductive voltage will appear between the 'live' and the other two conductors. An SPD on the mains supply will limit this surge to a safe level.

6.5 *Cable layout problems associate with cables entering a building at different locations*

In practice, signal cables frequently enter buildings at points remote from the main distribution board earth terminal which is the earth reference point for earthed equipment in the building. What then? SPDs are fitted on both the signal line and the mains supply *(as described in section 6.4)* to provide protection to the equipment served by the cable. However, there is a very long cable path back to the earth terminal. How can we mitigate the effects of this? There are several possibilities: -

a) Equipment relatively isolated: no signal cable links to other equipment in the building; earth cable not shared with other equipment – see section 6.5.1.
b) No internal signal cables: but shared earth path *(more likely)* – see section 6.5.2.
c) Internal cables: earth path not shared – see section 6.5.3.
d) Internal cables: with shared earth paths – section 6.5.4

6.5.1 *Equipment relatively isolated*

A typical example of a device which is *'relatively'* isolated is a telephone. A lightning surge lifts the potential of the cable relative to the local ground. The SPD operates and surge current passes down the surge protector earth conductor. An inductive transient develops across the earth conductor. However, the fact that the telephone is isolated, meaning it has no other connections to ground then damage is usually avoided.

6.5.2 *No internal signal cables (with shared earth path)*

Again, the equipment could be a fax machine or modem, but one which this time shares an earth as part of the mains earth system *(e.g its power is derived from the mains).* If fitted with an SPD the fax machine should survive. Had it not been protected, the surge current would have damaged the fax machine and a mains transient would still have occurred.

6.5.3 *Internal cables (no shared earth path)*

An example of an internal cable with no shared earth path, could be a modem serving a computer or WiFi router. At least some of the surge voltage developed across the earth cable may appear on the link to the computer, so there is still the possibility of damage to it. If the surge earth path cannot be shortened in practice, the modem with its SPD should be moved closer to the computer and all earthed together to the same point. Novaris makes combined mains and signal line protectors that are ideal for these type of applications.

6.5.4 *Internal cables (shared earth path)*

This combines the cases discussed in 6.5.2 and 6.5.3. Transients on internal cables and the mains supply are possible.

6.5.5 *Summary*

There is no easy way of handling the situation when cables enter a building at locations remote from the main earth terminal. If possible, the cables should be re-routed. If not, SPDs should be fitted to each device where the cables terminate to them and earthed to the local device earth. Where this equipment is linked electrically to vulnerable or strategically-important items of equipment elsewhere in the system, surge protection should still be used to protect all the equipment. Poor cable layout should not be used as an excuse for omitting surge protection which can still reduce significantly the risk and/or severity of damage.

6.6 *Ground electrodes, ground impedance and surges*

6.6.1 *General*

As we have seen earlier, lightning discharges to ground set up large transient voltages, with respect to local ground, on incoming cables. So far, in dealing with surge protection, we have assumed a connection to ground without considering the detailed implications. There are questions worth asking. 12

Why have a connection to ground at all? Why not just insulate the system and stop surge currents flowing at all, rather than bothering with low inductance star-point earths and the like?

The answers stem from the huge voltages and currents involved in lightning discharges. The voltage is so great that stroke current can be regarded as coming from a constant current generator. After all the lightning leader managed to get to the ground from the cloud with no conductor, so insulation will never work, our only hope is to control its path. To protect the structure of a building we might try to make it emulate an aircraft by enclosing it in a metal skin and placing it on insulating stilts (back to our ideal *'metal box'*?). But, apart from amusing us, nothing would be gained for two reasons: –

a) There will be connections to ground through the mains supply and other services that will defeat the insulation.
b) It would be extremely expensive.

Having accepted that our building is irredeemably anchored to the ground, do we need to bother about ground impedance? Suppose we are responsible for a remote monitoring outstation. There is one incoming cable from a transducer and a radio telemetry transmitter which is solar powered with no mains supply connection. This is an approximation to the isolated telephone or fax machine considered in section 6.5.1 and a ground connection may not be necessary. However, there are two reasons why sinking a ground rod at the outstation may still be worthwhile.

c) If the transducer cable is long, there may be sufficient voltage caused by a ground potential rise to cause flashover from the cable, through the telemetry equipment, to the fabric of the building.
d) There is also a risk, although small, that someone in the outstation, with feet at local ground potential, might receive a shock from touching the equipment during a storm.

These possibilities can be avoided or alleviated by sinking a ground rod at the outstation and fitting an SPD, as shown in figure 21, with the SPD earth as the star-point.

Provided star-point earthing is used, ground impedance is **NOT** critical for surge protection of electronic equipment.

Note : What is generally measured, and referred to, is ground resistance. In this publication, ground impedance is preferred as a reminder that there will always be inductance in series with the resistance and the voltage generated by this inductance will dwarf that generated by the resistance.

There is little point struggling to achieve, say, a 1Ω ground impedance *(the type of figure associated with large plant such as power stations).* That is why relatively little tends to be said about ground impedance when surge protection of electronic equipment is considered. The advantage of a relatively low ground impedance is illustrated by figure 22. The equipment shown has two signal cables, each protected, with a further SPD on the mains electricity supply. The equipment is therefore well-protected and will not be damaged. However, surge current travelling down one signal cable passes through the ground impedance, developing a voltage across it. This voltage will be *'seen'* at the remote end of the other signal cable. The higher the ground impedance, the more the surge can be viewed as being *'transferred'*. See Appendix B for a simple model illustrating the effect of ground electrode resistance.

6.6.2 Recap

- For protecting a single installation, a very low ground impedance is not necessary.
  A multi-installation as a whole will benefit from low ground impedance.
  There is no magic figure for an acceptable level of ground impedance.
- The ground impedance achieved will in many cases be determined by the characteristics of the ground, the connection systems and available time and funds.

See Appendix D for further reading on this subject.

6.7 Connection to the structural lightning protection system

As may be apparent from section 6.6, structural lightning protection is provided on the assumptions that: –

a) The building WILL be struck.
b) When it is, the consequent damage from the large currents flowing through the building structure can be considerable.

The purpose of structural protection is to define a path for lightning current to flow to ground as directly as possible via a system of down conductors rather than the building structure. The voltages developed between lightning conductors and the electrical system, if isolated from each other, can be enormous enough to cause destructive flashover. For instance, 50kA flowing through 20Ω develops 1 million volts! It is therefore safer to bond the two systems. The preferred method is by a cable from the main earth terminal *(the system star-point)* by as direct a route as possible to a point on the down conductor system close to the soil or below, such as at the earth mat itself. See figure 23.

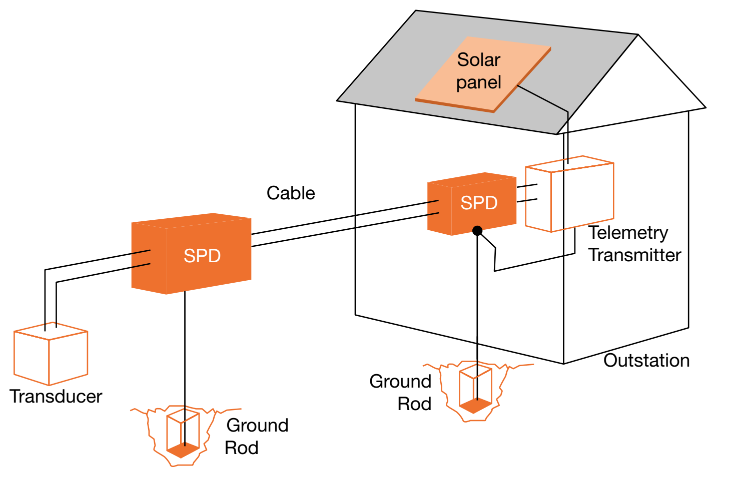

Figure 21 Outstation installation - with ground rod

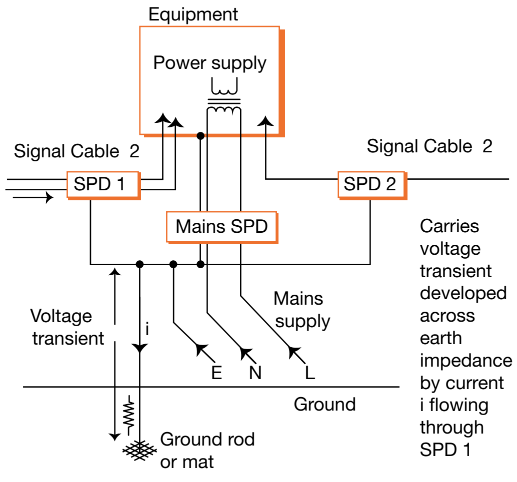

Figure 22 Advantages of low ground impedance

This is no more than a brief summary and is intended to raise awareness. To avoid straying beyond the scope of this document, we recommend consulting an appropriate standard such as AS1768 which covers this subject in detail.

6.8 The other end of the cable

If you are responsible for protecting equipment at both ends of a cable *(e.g., an installation involving more than one building or a telemetry link with a remote sensor)*, then treat both ends of the link in the same way. Equipment at each end is connected by the cable to the local ground at the other end *(in fact, SPDs make sure this is the case)*. Without protection, a lightning surge can cause a large earth potential rise to form between these ground connections.

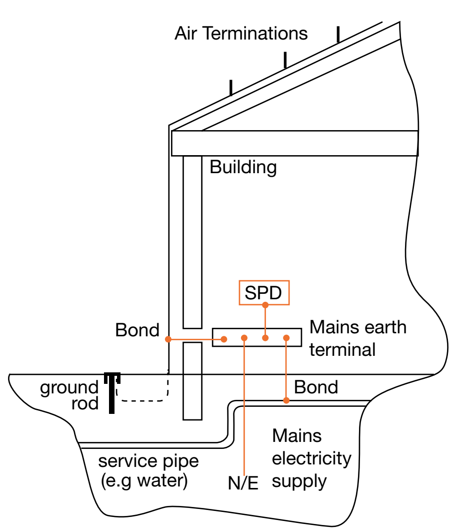

Figure 23 Bonding a structural lightning protection system to the system star-point

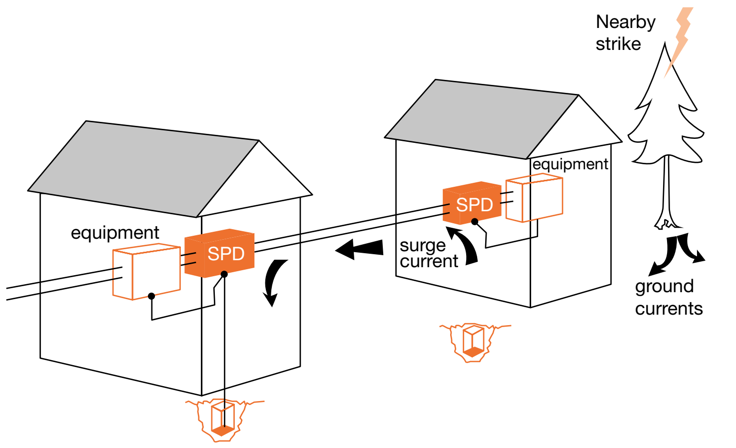

Figure 24 Bonding a structural lightning protection system to the system star-point

Fit an SPD at each end. Surge current can then flow harmlessly between the two ground points through the SPDs, rather than destructively through the equipment *(figure 24)*. As always, keep the SPD earth cables short or, where possible use the DIN mounting rail as the earth connection.

7 SIGNAL LINES AND CABLE SCREENS

7.1 Shielded cables and earth loops

To prevent unwanted pick-up of stray electric fields, cables carrying low- frequency low-level signals often use an overall screen or shield. Single-point earthing is usually favoured to break earth loops which can cause interference to the low level signals on the cable cores. In situations where SPDs are not necessary, the simplest method of achieving a single-point signal earth is simply to connect the screen at one end of the cable only *(figure 25)*. However, where SPDs are fitted, more than one earth/ground connection is necessary.

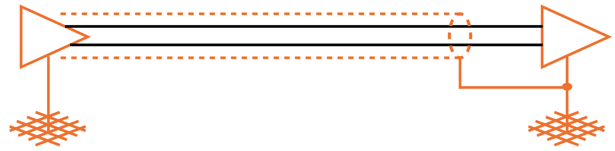

Figure 25 Earthing a cable screen at one point only

When SPDs are included in the system it is usually physically convenient to provide the break in the screen circuit at one of the SPDs – see figure 26. This diagram shows the ideal earth positions for lightning protection, but often the real situation will be more like that shown in figure 27, in which case the need for the SPDs to be mounted as close as possible to the transmitter and receiver will be benificial.

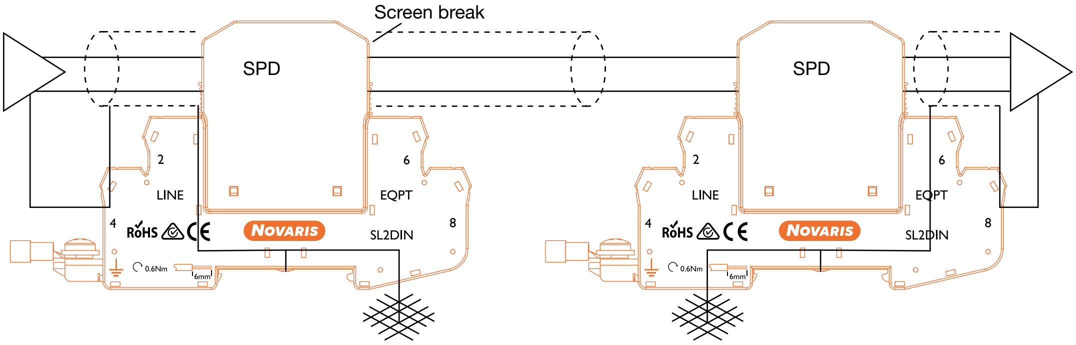

Figure 26 Earthing a screen circuit at an SPD

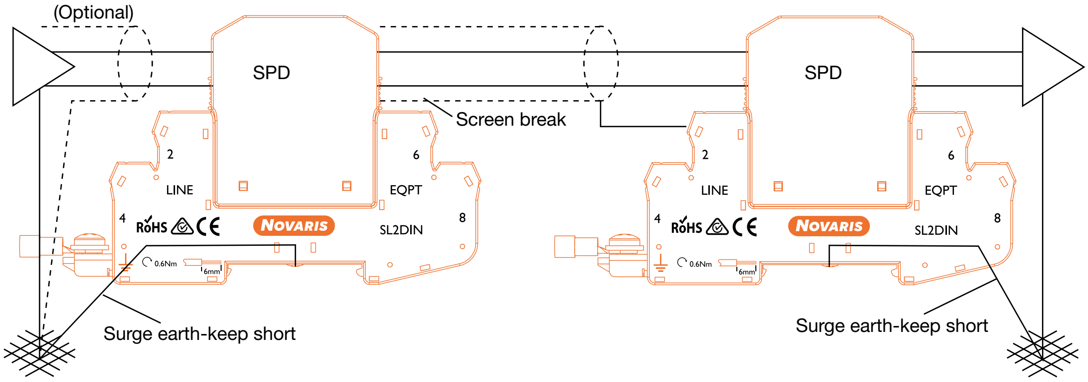

Figure 27 An earth set-up for a cable screen where the SPD is connected to a star-point earth

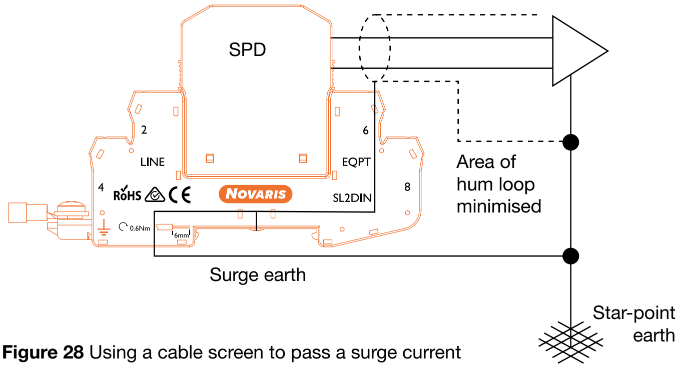

Figure 28 Using a cable screen to pass a surge current

Note: In figure 27, if the screen shown as optional at the left-hand side of the diagram has a total conductor cross-section of 2.5mm^2 or more, it can be used as the surge earth.

Another situation likely to be encountered is illustrated by figure 28. In this case, there is an appreciable length of cable connecting the SPD and the equipment to the star-point earth with the possibility of large transient voltages In this case, the cable screen can serve as a surge link to reduce the transient. This, however, creates a loop which can cause problems, depending upon the system. Minimising the loop area by running the surge earth cable close to the screen may be helpful.

7.1 Shielded cables and earth loops (cont)

Note that the cable screen break should be made with the screen clearly separated from metalwork, such as the SPD, which may be at a different potential. A 10mm separation, especially if the screen is well insulated, should normally be adequate. Alternatively, it may be an advantage for the surge current to pass down the screen, with its higher current capacity, rather than the inner conductors alone. This can be done by connecting the screen to one side of an SPD as shown in figure 29. The SPD maintains a break in any hum loop as described earlier.

For further reading on this subject, see Appendix D.

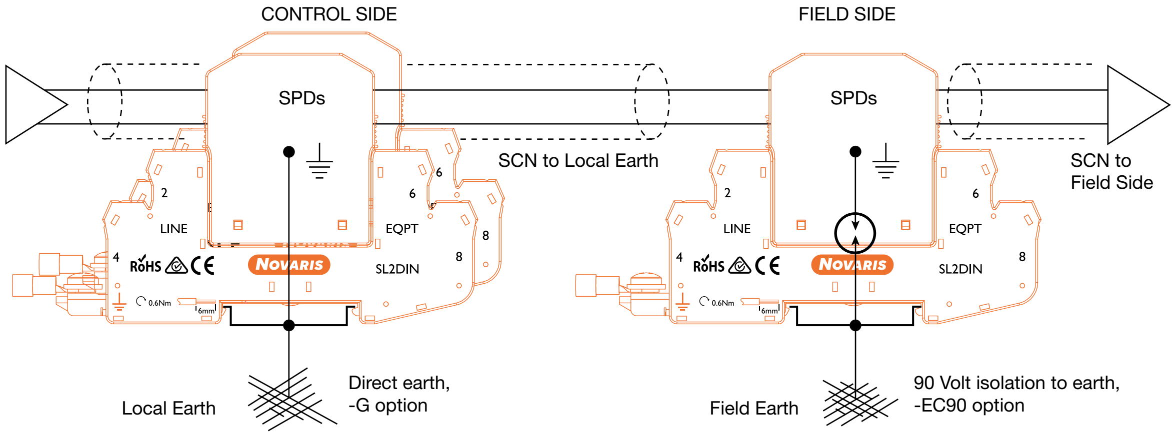

Figure 29 Using a cable screen to pass a surge current

Where it is required to keep a continuous cable screen/shield from the controlling equipment right out to the field equipment/instrument for noise suppression or EMC reasons then earth/ground loop currents can become problematic if SPDs are installed at multiple locations along the circuit. To overcome these problems Novaris manufactures two types of base unit for most of their signal line and data SPD's. A directly grounded base or SPD has no suffix or the suffix -G. These bases have a solid ground connection and are normally installed and grounded to the controlling equipment. Isolated SPD's and bases carry the suffix -EC90 and these use a GDT to isolate the earth connection during normal use thus isolating and interrupting the path for any ground loop currents to circulate. When the -EC90 unit is exposed to a surge then the GDT fires momentarily to shunt the surge current to ground, protecting the equipment, and then returns to an open circuit. The -EC90 units are normally installed and grounded to the field equipment or instrument, Figure 29 details the most common application of the two types.

7.2 Protecting baseband transmission systems using co-axial cable

Co-axial cables are used in a number of lower frequency applications such as analogue measuring instruments and CCTV cameras. The type of SPD that can be applied is determined by the type of connector used and the co-axial cable characteristic impedance. Novaris has a full range of SPD's to cover all the connector options that allows the SPD to be simpley pluged in at the cable termination points as required.

Where the equipment is separated and earthed via different grounding systems then it is often necessary to use an indirectly grounded SPD at the field end of the co-axial cable, the Novaris options for this application are known as the EC90 and will eliminate any ground loops whilst still providing a ground path for surges when they are present.

7.3 Protecting high-frequency co-axial cable systems (e.g., antenna feeds and TV)

For frequencies of tens of megahertz *(MHz)* and above, an SPD must have very low capacitance. Transmitting applications also require high voltage operation. Wideband co-axial SPDs, such as the Novaris CN series, based on gas discharge tube protection elements in special housings, are designed for the purpose. Insert an SPD close to vulnerable equipment where there is the best available ground point. The installation rules for these are exactly the same as for all other SPDs. The only differences are the very low capacitance of these devices and their symmetry *(i.e., they can be mounted either way round).* See figure 30 for a typical installation.

The co-axial cable shield should be bonded to the base of the antenna tower, as shown and at the entry to the building to avoid direct strike current flowing down the feeder into the building. If the tower is tall, the cable should be bonded to the tower every 10m or so to avoid flashover between the tower and the cable. Novaris offers a range of bonding kits for this application to suit feeders from 1/4 up to 1-5/8 inch idiameter, they are known as the Ekit.

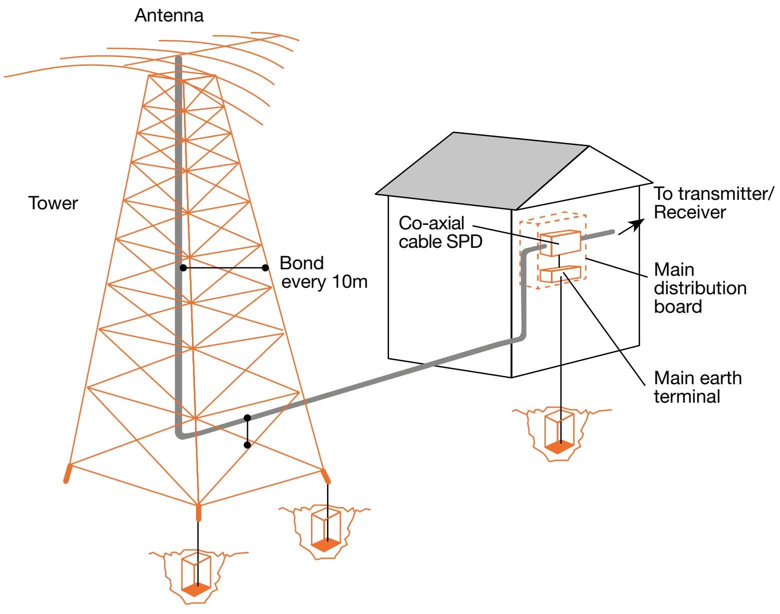

Figure 30 Protection for a high-frequency co-axial antenna cable system

7.4 Protecting the mains supply

Transients can be introduced into a system by the mains supply *(as with any other cable)* and, as we saw earlier, can be caused when surge currents pass down signal lines and into the mains earth conductor. In general, mains transients are less damaging than at first sight because power equipment is usually more robust than electronics but surges coming from the grid can still cause heavy damage due to the fact that the power is usually distributed to multiple equipments as shown in the example of an office in Figure 31.

The mains supply is also likely to carry disturbances within or close to a site, caused by the switching of heavy current devices such as motors.

The optimum protection scheme is a combined one deploying high surge rating SPD's at the distribution board and progressively lower rating SPD's down to individual sub-boards or devices.

Figure 31 illustrates, by way of an example, a combined protection system for a modern office based on the use of various Novaris SPD's. This does not of course provide a universal solution. Contact Novaris for guidance on individual situations.

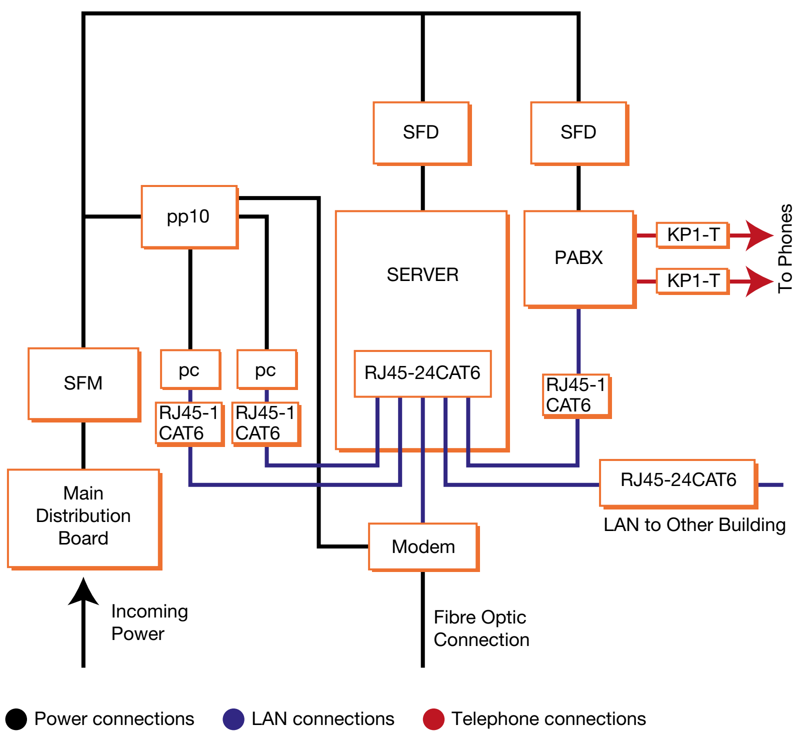

Figure 31 Block diagram of a protection system for an office building

7.5 Telecommunications earthing

The design of a telecommunications earthing system needs to allow for the protection of people, the protection of equipment and provide an equipotential plane to allow the safe dissipation of surge currents caused by direct lightning strikes to the telecommunications structure and to incoming services.

At a typical telecommunications site a service earth will be established. This may be as simple as a single earth rod or an earthing system comprising the tower and building earths. Regardless of how these are configured all site earthing systems, including the power utility earth must be bonded together so that in the event of a disturbance the whole site rises to the same potential.

Australian standard AS3015 covers this subject in detail.

At the consumer equipment level multi service protection devices *(MSPD)* are employed to protect telecommunications and IT equipment from damage. An MSPD provides combined protection for power and signal lines that may comprise copper pairs *(VDSL)*, ethernet, or coaxial feeders from antennas. Within the MSPD the AC earth and signal SPD protective earths are bonded via an SPD component with a breakdown voltage of more than 400V DC *(generally a gas discharge tube)*. This is to prevent an AC earth fault from being transferred to the signal equipment.

7.6 Integrated earthing for process systems

7.6.1 Introduction

The earthing arrangement for a single SPD and equipment is logical and easy to apply. However, the earthing arrangements for a process system can become daunting when faced with the need to consider all the required *'separate earths'* for noise rejection, intrinsic safety (*see also section 7.7)* and electrical safety. This section suggests a practical solution, well-proven on many industrial plants, which can be applied to most process plant design, either at the pre-construction stage *(engineering)* or, in some cases, during plant modifications and updates.

7.6.2 Preferred earthing methodology for control systems

For an SPD to provide optimum protection, there needs to be a coherent earthing methodology.

Surge currents, whether caused by direct strikes or by changes in local earth potential, need a low impedance path to earth. Such currents entering the marshalling cabinet through the instrument cabling are diverted to earth by the SPD and its own earth busbar from which current should flow to the system earth without flowing through any other earth connection. All other earths should be connected to the SPD earth busbar at one point only. Mounting the DIN rails on a metallic back-plate and connecting this plate to the earth busbar with a solid link or heavy cable is the optimum. All the SPD's should use the DIN rails as their primary means of earthing thus providing the lowest impedance path to the local earthing system in the ground.

7.7 Hazardous areas – earthing for lightning protection

The subject of the use of electrical/electronic equipment in potentially explosive atmospheres is large and complex, and this document can therefore only address the earthing of SPDs used in these systems. For more details about surge protection in hazardous areas, consult the Novaris application note 0015-D17V4.

The subject of surge protection in hazardous areas and also explosion proof housings is highly regulated and certified. Before designing any systems that are in these areas then there are at least two standards that should be studied in detail, these are EN/IEC 60079-0, EN/IEC 60079-1.

Novaris manufactures a range of intrinsically safe SPD's for use in hazardous areas which are all independantly certified to the standards noted above, contact Novaris for details or view www.novaris.com.au.

For further reading on the subject, see Appendix D.

8 APPENDICES

8.A Appendix A – Novaris golden rules for surge protection installation

1. Apply protection at all points of entry to a building or housing.
2. Mount the surge protection as close to the equipment as possible.
3. Bond the surge protection and equipment earths together at each location.
4. Keep wiring as short and straight as possible.
5. Use the DIN mounting rails as the primary ground connection for the SPD's.
6. Protect the sensitive circuits first.
7. Avoid having multiple earths in the same installation, bond earths together where possible.
8. Refer to AS 1768 for detailed practical guidance on appropriate ratings for SPD's.
9. In areas with poor grid regulation use power SPD's designed to deal with Temporary over Voltage (ToV).
10. Use purpose designed Over Current Protection devices (OCPD) such as the Novaris SCB to protect power SPD's rather than fuses and circuit breakers.

8.B Appendix B – Ground electrode resistance and surge current sharing, a simple model

Although a simplification, this model provides a useful guide as to what happens in reality without getting too mathematical.

Consider two installations, 1 and 2, linked by a cable, each with a ground electrode system and with one fed from a remote cable *(figure 32)*. A lightning strike causes a surge on the cable relative to local grounds 1 and 2. Installation 1 has an SPD fitted which, in this simple model, is assumed to provide a short circuit for the surge.

The situation can be represented by the circuit diagram reproduced in figure 33. In this, V is the transient voltage source and R is the source resistance *(including the resistance of the cable).* Rg and rg are the ground electrode resistances of installations 1 and 2 respectively and r is the resistance of the interconnecting cable. For the sake of simplicity, only resistance and not impedance is considered. We already know that the inductance in the earth connections will make the real situation much worse than this simple model predicts.

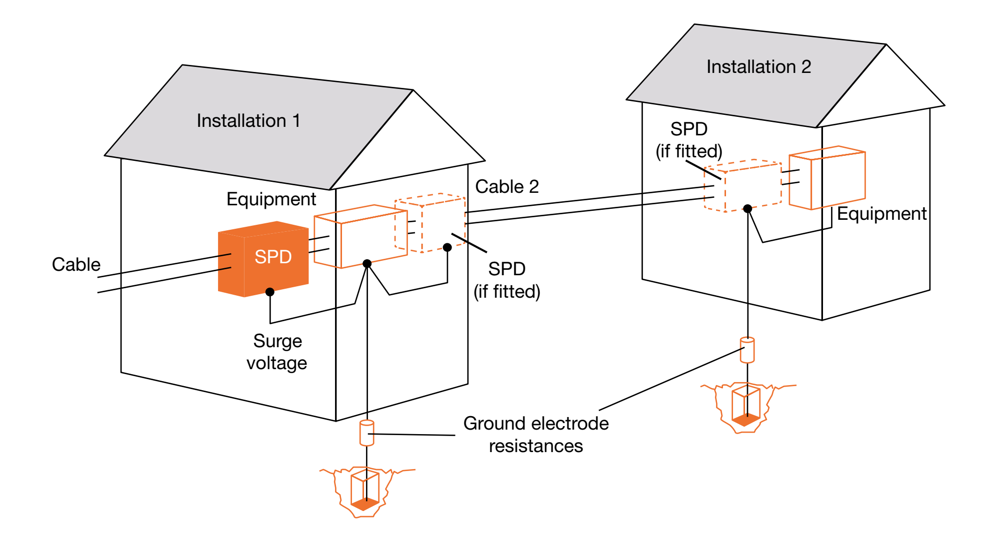

Figure 32 Model system with two grounded and linked installations

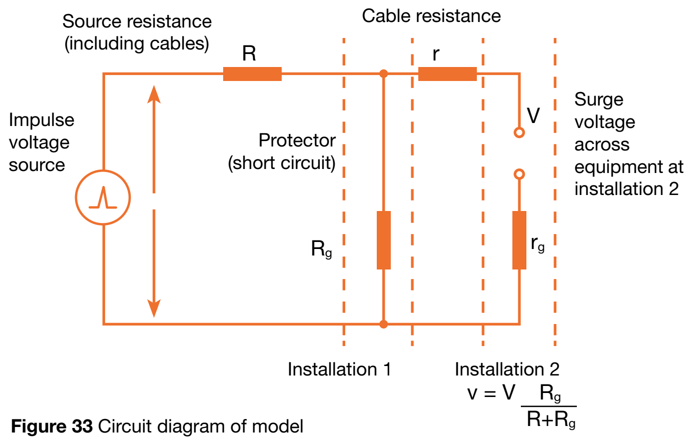

Figure 33 Circuit diagram of model

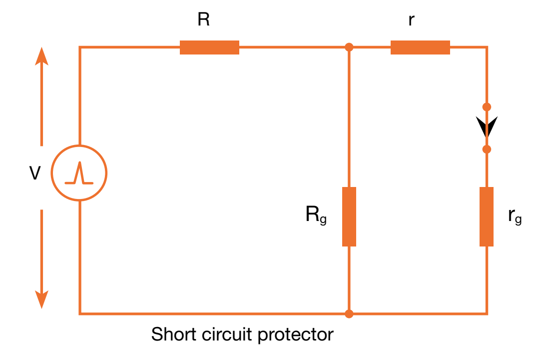

Figure 34 Operation of SPD in installation 2

First, we assume that installation 2 is unprotected and calculate the surge voltage it receives and then calculate the surge current when an SPD *(again acting as a 'perfect' short circuit)* is fitted.

From the diagram in figure 33, the received surge voltage is: –

$$v = V \times R_g/R+R_g$$

When the SPD in installation 1 operates, it closely approximates to a short circuit *(figure 34).*

From figure 34: –

$$i = \frac{V \times R_g}{R\,(R_g+r+r_g)+R_g(r+r_g)}$$

$$i = \frac{V \times 1}{R\,(1+[r+r_g]/R_g)+(r+r_g)}$$

This looks a little obscure, so it is helpful to consider the two extreme cases of no ground electrode and a perfect ground electrode.

No electrode:	*Perfect electrode:*
$R_g = \infty$	$R_g = 0$
$i = \frac{v}{R+r+r_g}$	$i = 0$

As might have been expected, the higher the ground resistance at installation 1, the bigger the surge that installation 2 receives.

8.C Appendix C – Glossary

Bonding
Making electrical connections, not necessarily for carrying current but with the intention of ensuring a common equipotential as far as is practical.

dc
Direct current – in common usage used in 'dc voltage' to describe a uni-directional voltage.

Earth bond
A short bonding conductor fitted to limit the voltage between the earth connections of an SPD and the protected equipment.

Equipotential zone
An area where people attempt, by providing electrical conductors, to keep equipment at the same potential or voltage. In most practical cases it can be approached – but never reached – since voltage differences appear across conductors when current flows through them, especially high frequency surge currrents.

GDT
Gas discharge tube.

Impedance
The property of a conductor which inhibits the flow of current.

Inductance
The property of a conductor which inhibits changes in current, due to the magnetic field created by the current.

kV
kilovolt; (1kV = 1000 volts)

8.C Appendix C – Glossary (cont)

Let-through voltage
The transient peak voltage present at the output of a surge protection device and to which the protected equipment is subjected. As we have seen in reality the let-through voltage is the addition of the SPD and earth path voltages

MOV
Metal oxide varistor.

SPD
Surge protection device.

Surge; transient; transient overvoltage
Terms used loosely and interchangeably to indicate the presence of an abnormally high voltage which is present for a brief interval only. In the context of this document, we are generally referring to surges caused by lightning activity.

Surge protector; surge protection device (SPD); transient protector (see below)
Interchangeable terms for devices which are intended to prevent damage caused by transient voltages.
Other terms for SPDs can be derived by combining any one of the words in the left-hand column with any one of those in the right-hand column. Different terms are more commonly used in certain geographical regions than others.

Surge	*arrestor*
Transient	*barrier*
Overvoltage	*suppressor*
Lightning	*protector*
Spike	*protection device*

Transient Voltage Surge Suppressor (TVSS) is a combination of these terms and is a common term in the USA and their dominions, but does not indicate any different mechanism of operation than a standard SPD.

True earth
The point of zero voltage to which the voltage of any other point can be referred. In practice this does not exist under surge conditions.

8.D Appendix D – Further reading

1. Lightning Physics and Effects, Valdimir A. Rakov and Martin A. Uman, Cambridge University Press 2003
2. Overvoltage Protection of Low Voltage Systems, Peter Hasse, Peter Peregrinus Ltd 1992
3. Lightning Protection for People and Property, Marvin M. Frydenlund, Van Nostrand Reinhold, 1993
4. Martin A Uman, *Lightning,* Dover 0 486 64575 4, 1969
5. William C Hart and Edgar W Malone, *Lightning and Lightning Protection,* Interference Control Technologies Inc, 1988
6. Ralph Morrison, *Grounding and Shielding Techniques in Instrumentation,* Wiley Interscience, 0 471 83805 5, date 1986
7. Henry W Ott, *Noise Reduction Techniques in Electronic Systems,* Wiley Interscience, 0 471 85068 3

EN/IEC 60079-0 and -1
Novaris Application Note 0015-D17V4