Method for the Design of Lightning Protection, Noise Control And Grounding System at a Telecom Facility INTELEC® 2014

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Abstract - There is generally an absence of a methodology that explains the logic behind the design of the lightning protection, noise control and grounding system for a telecommunication facility.

Common types of telecommunications sites that require grounding include radio sites, roof mounted cabinets or shelters, ground mounted cabinets and shelters, satellite sites, data centers, cable chambers and central office buildings. The methodology behind the design of the grounding system should be versatile enough to apply to any facility.

There is neither a single rule nor application of a standard that can eliminate the risk of lightning and its transients and noise at telecom sites. A holistic approach that does not miss critical parts of the design is required. The design of a telecommunications grounding system needs to take account of the following 5 points, typically but not always in this order of importance:

1. Indoor grounding arrangement
2. Outdoor grounding arrangement
3. AC surge protection for incoming power and DC surge protection for tower mounted radio units.
4. Surge protection & grounding of telephone lines and RF feeders.
5. Direct strike lightning protection

This paper discusses a methodology that covers all aspects of the grounding design discussed above.

The paper looks at examples and case studies of how this methodology is applied to various types of facilities. It also looks at commonly used telecommunications grounding standards in Europe and the USA and discusses how the methodology fits in with existing standards and codes. It also discusses relevant ITU Guidelines used for design of grounding systems.

At the end of this paper, the attendees will be able to apply the methodology to their own facilities while complying with codes and standards relevant to their country. They will be able to come up with logical grounding system designs or modify existing designs and understand the reasoning and thinking behind incumbent practices.

1. INDOOR GROUNDING ARRANGEMENT

In the opinion of the author the indoor grounding arrangement is the most important aspect of the grounding system design. This is also the aspect of grounding that is more likely to contribute to equipment faults in comparison with the 4 other points. Generally though, the implementation of this aspect is probably the one which has the lowest relative cost. Not surprisingly, it is sometimes given the least importance.

For example, it is not uncommon for engineers to insist on a target resistance value, say 5 ohms for outdoor grounding at cellular sites. But it is uncommon that one picks up ground loop problems inherent in the layout of the indoor grounding design. The existence of a ground loop is far more likely to contribute to a future equipment fault then a high ground resistance value, say of 20 ohms.

There are several standards and guidelines referred to in this paper which benchmark the design and the layout of the indoor grounding arrangement

A. ITU-K27

The ITU K series of guidelines deal with protection against interference. The Guideline ITU K27 is Titled “Bonding Configurations and Earthing Inside a Telecommunications Building.”

The two methods commonly used in telecommunications facilities around the world are described in ITU-K27. These are the Star-IBN and the Mesh-IBN (IBN stands for Isolated Bonding Network).

In the Star-IBN System there is a single point connection window or SPCW via which the indoor grounding system is connected to the ground electrode system. This is usually in form of a ground bar but can also be a ground ring inside the telecommunications facility. See Figure 1.

In the MESH-IBN the components inside the telecommunication facility (e.g. equipment frames) are interconnected to form a mesh-like structure. This may, for example, be achieved by multiple interconnections between
cabinet rows, or by connecting all equipment frames to a metallic-grid, “bonding mat” or “signal reference grid” extending beneath the equipment. The bonding mat is, insulated from the Common Bonding Network (CBN) of the adjacent room or building. If necessary the bonding mat could include vertical extensions, resulting in an approximation to a Faraday-cage. The spacing of the grid is chosen according to the frequency range of the expected noise. While there are multiple connection paths within the equipment room, there is only one single point via which the MESH-IBN connects to the external ground electrode system. See Figure 2.

These methods look similar to MESH-IBN but there is a clear attempt to not have isolation but rather deliberate multiple points of connection around the mesh to a CBN. This would be in form a physical earth ring around the floor of the room.

In many countries, this method is more common in data centers that are generally AC (and more recently High Voltage DC) powered as opposed to traditional telecommunication equipment room which are low voltage DC powered. Another reason that the mesh method gets used is where the area to be considered gets too large for it to be practicable for a star system to be maintained. The Star-IBN system is preferred to the mesh method in telecommunications facilities powered by DC power. In modern day facilities there is a growing overlay of AC powered and DC powered equipment within the same room and it is possible that this type of system may become more common in future. Figure 4 below shows a typical single point connection for Star-IBN and Mesh-IBN system.

There is another type of indoor grounding arrangement mentioned in ITU-K27. This is called the MESH-BN, or Mesh Bonding Network.
B. ETSI EN 300 253 V2.1.1 (2002-04)

The ETSI EN 300 253 is titled “Environmental Engineering (EE); Earthing and Bonding Configuration Inside Telecommunications Centres”

One bonding configuration only is selected from ITU-T Recommendation K.27 (CBN/MESH-BN) and tailored ETSI EN 300 253. While K27 deals with grounding at building and installation level, the ETSI standards gets into some detail of bonding at equipment level.

C. Telcordia Generic Requirements GR-295

Telcordia GR 295 is titled “Mesh and Isolated Bonding Networks”. This document is very comprehensive and gets into significant detail of how to construct a Star-IBN, Mesh-IBN and MESH-BN system. There is consistency in methodology recommended in ITU-K27 and Telcordia GR295.

D. Motorola R56 Standard

In the USA, Motorola Standard R56 has been adopted in full or in part by many organizations. This document provides many practical guidelines for installation of telecommunications sites. The example in Figure 6 brings the Star-IBN concept into a format that can be directly applied to telecom facilities

A clear adoption of one of these indoor grounding methods is essential at a telecommunication facility. It should be stressed that the chosen methods shall be one of the ITU methods and not a hybrid between these methods. The reasons for having a good indoor grounding arrangement are to provide:

- safety from electrical hazards
- reliable signal reference
- satisfactory electromagnetic compatibility (EMC) performance
- transient control
- noise control
- minimal effects of currents via unwanted paths

E. Equipotential Bonding of Indoor Grounding to AC Ground

There is worldwide consensus on equipotential bonding of the indoor grounding system to the AC electrical ground. Figure 7 below shows the method of bonding for various power systems. Certain country specific standards may require a disconnect link between the AC ground and the Telecommunication Main Earth Terminal (MET) or Main Ground Bar (MGB)
2. OUTDOOR GROUNDING ARRANGEMENT

Indoor grounding principles above are applicable to buildings, shelters and equipment rooms but not to cabinets and outside plant. The outdoor grounding system is an essential part of any telecommunication facility including outdoor cabinets and outside plant.

There are 4 key elements to the design of the outdoor grounding system that are considered here:

A. The geometry of the grounding system.
B. The resistance to remote earth.
C. The interface between parts of the grounding system, i.e. the connection between tower and equipment ground electrode, the connection between indoor and outdoor ground electrode.
D. The choice of material used to construct the outdoor grounding system.

A. Geometry

Ground electrodes formed into a ring around a building, shelter or a tower are common. The author has often encountered the question on the need for a ring when there is only a single point of connection between the outdoor ground and the indoor ground and not multiple connections around the ring.

In these situations, an earth ring is not required for connections around the structure. However a symmetrically laid ground electrode system provides an even voltage gradient around the structure and a low earth potential rise (EPR) in the center of the structure during lightning dissipation to the ground. Lower EPR in the ground makes the management of the lightning energy easier. By minimizing the risk associated with lightning currents flowing via equipment and discharging into the base of the building or to the other side of the building.

Until recent developments in software, it had not been possible to model the EPR caused by lightning dissipations into the ground. However, due to the complexities in changing frequencies and impedance of the ground at different phases of a lightning dissipation, any mathematical modeling will contain significant inaccuracies and approximations. The ring earth design based on the above intuition has served the telecommunication industry well and is unlikely to be superceded by methods calculated by mathematical modelling.
ITU K56 Recommendation, entitled “Protection of Radio Base Stations Against Lightning Discharges”, provides the depiction of the grounding system with ground rings around the building, around the masts and in the perimeter of the compound as shown in Figure 8 and 9.

Telcordia Technologies Generic Requirements GR-3171-CORE, entitled “Generic Requirements for Network Elements Used in Wireless Networks”, makes extensive recommendations on the use of ring ground electrodes. This document states the use of ground rings as a method to “minimize the differential potentials and induced current flow across the facility”. Like ITU K56, Telcordia GR3171 also promotes the use of ground rings around buildings and towers. Both the documents mentioned above have further specific requirements for the installation of outdoor ground electrode systems.

Where the space constraints do not allow a ring encircling the whole structure, alternative arrangements can be used. However, attention needs to be paid to keep these installations as symmetrical as possible so that they produce low EPR. Understanding the reasoning for the use of ground rings will help design alternative geometry that achieve similar results.

B. The Resistance to Remote Earth

It is widely accepted in the industry that 5 ohms resistance to remote ground is the highest allowable value for any telecommunications facility. This value is sometimes not achieved in areas of high soil resistivity and on sites with limited space available to install an earth grid (i.e. at roadside cabinets and in built up areas).

Lower ground resistances between 0.5 ohms to 2 ohms will be required at more complex sites like Central Offices or MSC, larger repeater sites and satellite stations.

The ground resistance values are defined by telecommunication operators internal standards, guidelines like Motorola R56, country specific standards and standards of telecommunications equipment manufacturers. ITU K series recommendations do not have a specific ground resistance values.

Ground resistance is commonly measured at telecommunication sites using methods like the “fall of potential” or “slope method”. A detailed description of these methods is outside the scope of this paper.

Proper levels of ground resistance are often achieved by installing a pre-determined design. This is particularly common with cell sites where there is a desire to have consistent designs at multiple sites. This approach can still produce varying results due to difference in the soil resistivity at various sites.

A more scientific approach to designing the ground electrode would be to carry out a soil resistivity test prior to the commencement of any installation. This values can then be used as input into empirical formulae or software to predict the number and dimension of ground electrodes required to meet the target ground resistance. This method is recommended for larger sites where resistance values of lower than 5 ohms is desired or in areas with high soil resistivity. A common measurement technique used to determine soil resistivity at varying depths is the Wenner 4 Point method. The description of this method is also outside the scope of this document.
Reference to ground impedance is made in certain documents. However, ground impedance can not be easily measured and hence it is difficult to quantify and specify.

The geometry can also involve considering the shape of the conductor used in the grounding system. It has been argued that the geometrical difference between a flat tape as opposed to round conductor can provide lower impedance on the telecommunication system at higher frequencies. This is based on the knowledge that flat tape has lower series inductance and high capacitive coupling to ground due to a larger surface area. As impedance measurement of a ground electrode system is highly subjective and difficult to measure the choice of conductor based on this geometrical difference will continue to be based on intuition as best guess rather than quantifiable differences.

C. Interface Between Grounding Systems

The typical interface between the tower ground and the building or equipment ground is shown above in Figure 6A, 6B and Figure 7.

It is common to have a single connection between the building or equipment ground and the indoor grounding system via the single point connection window (SPCW). This is usually the Main Ground Bar (MGB) in USA & Canada, Main Earth Terminal(MET) in Europe and Service Earth Bar (SEB) in certain countries in Asia.

D. Choice of Grounding Materials

Conductor

The two most common conductors used for horizontal connections in the ground are copper and galvanised steel. Copper has excellent electrical conductivity and offers good corrosion resistance in a wide range of soil conditions making it an ideal conductor. However it is also a relatively expensive material and galvanised steel is sometimes used as a lower cost alternative. Copper is used either as stranded conductor or as flat tape usually 25x 3mm or 1” x 1/8”.

Galvanized steel is used commonly as a flat tape ranging in width from 20mm to 50mm, (7/8” to 2”) and ranging in thickness from 3mm to 5mm, (1/8” to 3/8”). ITU K56 recommends a minimum cross sectional area for copper as 50 mm². Standards in the USA recommend #2 wiresize.

The much shorter life time of galvanized steel in ground than copper alternatives is generally well understood. In similar soil conditions, like sizes of copper and galvanized steel will offer approximate lifetime of 30-40 years and 10-15 years respectively.

Modern conductors like copper bonded steel are emerging in the market place. With adequate coating of copper, these can provide long lifetime similar to all copper conductors and the cost benefits of a steel conductor. At the time of preparing this paper, solid round conductors of diameter 8-13mm with suitable coating of copper are available as alternative to copper. The conductors are rugged also more difficult to handle due to stiffness. Copper coated steel tape conductor, with suitable amount of copper coating, are a possible future development. The flat shape will allow this conductor the have a similar level on installation ease, as that faced with galvanised steel tape. Stranded conductors with copper coated steel strands are also available as an alternative to copper.

The need for modern conductors is driven by increasing copper theft at telecommunication sites, the desire to have long grounding system life expectancy and the desire not to increase the net cost of conductors when considering alternatives.

Ground Electrodes

The three most common types of ground electrodes are copper bonded steel, galvanised steel and stainless steel.

Figure 11 below show the life expectancy and relative cost of these materials. The chart below are derived from the outcome of a study in the USA called “National Electrical Grounding Research Project”.

The results of this are summarized in “A Technical Report on The Service Life of Ground Rod Electrodes” by Chris Rempe.

Based on the graphs in Figure 11, copper bonded ground rods provide the best long term corrosion resistance relative to its cost. Galvanized steel can be a low cost option when short lifetime in the ground is acceptable. Stainless steel
provides the best corrosion resistance and by far the highest in cost yet it may be required in certain soil conditions for site specific corrosion reasons.

Ground rods can be extended to reach deeper in the soil by means of threaded or compression couplers. See Figure

![Image of couplers for extending copper bonded and steel ground rods](Figure 12: Couplers for Extending Copper Bonded and Steel Ground Rods)

**Grounding Connectors**

The three common types of connectors used in telecommunication are CADWELD (or other exothermic welds), bolted connectors and crimped connectors.

CADWELD connections are the most common type within copper based grounding system in large parts of the world. Some reasons for their popularity include high reliability, long life, low corrosion rate and low relative cost. This method can be used on a wide range of materials and shapes of conductors including tape conductors and vertical surfaces.

Bolted connectors are generally used with galvanized steel based grounding systems. CADWELD or exothermic welded connection can also be used with galvanized steel. In these systems the most common use of CADWELD or exothermic welded connections is copper cable to tape.

Crimped connectors can be used for cable to cable connections. However they cannot be used on other types of connections like tape to cable, tape to tape and cable to vertical surface like fence posts and tower members. Given that many types of connections exist at telecommunications sites the use of crimped connections across all the connection types at a site is less common.

Where dissimilar metals are used in the ground, care needs to be taken on long term effects of galvanic corrosion. This can be managed with choice of correct materials, by eliminating barriers between dissimilar metals and by applying water proofing with techniques like grease covered tapes.

![Image of typical grounding connections](Figure 13: Typical Grounding Connections Shows CADWELD, Crimps and Bolted Samples)

**Ground Bars**

Tinned and bare copper has been the material of choice for telecommunication ground bars for many decades. Recent increase in the rate of copper theft at telecommunication facilities has led to carriers and tower companies to look for suitable alternatives to flat copper for use as ground bars.

Alternative shaped ground bars which deter theft have been invented in the last few years. The example shown below in Figure 14 was invented in Virginia, USA and underwent significant testing for corrosion and electrical performance including UL testing.

![Image of theft deterrent ground assembly](Figure 14: Theft Deterrent Ground Assembly)
A study of the following alternative materials available for use as ground bars was undertaken by ERICO®.

<table>
<thead>
<tr>
<th>Materials</th>
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<tbody>
<tr>
<td>C11000 Copper</td>
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<tr>
<td>Copper Plated Steel (0.2 mil)</td>
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<tr>
<td>Copper Plated Steel (0.5 mil)</td>
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<tr>
<td>Galvanized Steel (3.9 mil)</td>
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<tr>
<td>Zinc-Nickel Alloy Plated Steel</td>
</tr>
<tr>
<td>Copper-clad Aluminum</td>
</tr>
<tr>
<td>Tin-Plated Aluminum (0.02 mil)</td>
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Table 1: Materials Considered in Study

The investigation included corrosion resistance, electrical performance and costs for the alternate materials for telecommunication ground bars.

Change of impedance tests and visual inspection was carried out after subjecting the earth bars to alkaline and acidic conditions to simulate long-term corrosion in soil. The simulation included salt mist treatment to IEC Standard 60068-2-52 and humid sulfurous atmosphere treatment to standard ISO 6988:1985.

- This investigation demonstrated that the earth bars that showed closest performance to solid copper earth bar were copper clad aluminum and tin plated aluminum. **Tin Plated Aluminum is considered the best alternative to copper earth bars.** In addition to the outcomes of the test it is known from the galvanic potentials table that tin permits compatibility with the various lugs and connectors including copper.

- Copper plated steel and galvanized steel showed similar characteristic to each other but had higher DC and AC resistance than copper and tin-plated aluminum even before the corrosion tests. **Some of these bars can be considered as alternatives to copper earth bar under certain conditions.**

- Zinc-Nickel Alloy Plated Steel and Stainless Steel either showed high DC or AC resistance or high corrosion and were deemed not suitable for use as earth bars. **These are not good materials to use as alternative to copper earth bars.**

3. **AC SURGE PROTECTION AND DC SURGE PROTECTION.**

The installation of the indoor and the outdoor grounding system addresses the safety, EMC, lightning energy dissipation and noise control system at a telecommunication facility.

Events that occur outside of the facility that could transfer a transient or a surge to the facility are not fully controlled by doing just the grounding. Part 3 of this paper will discuss the design of the surge protection system to protect against transients & surges that enter the facility via the power lines.

Part 4, will discuss the design of surge protection system to protect against transients & surges that enter via communication lines.

**A. AC Surge Protection**

Voltage transients or surges can couple onto power lines due to lightning strikes near power lines or other power system disturbances like switching. Lightning can couple onto power lines via a direct strike to the power line or capacitive and magnetic coupling from nearby strikes.

Surge Protective Devices (SPD’s) for AC application are covered in detail in IEC61643 suite of standards and IEEE Trilogy C62.4.1, C62.4.2 and C62.45. Additional IEEE standards exist for testing and application of SPD’s. UL1449-Edition 3 defines the “requirements cover Surge Protective Devices (SPDs) designed for repeated limiting of transient voltage surges” and is arguably the most onerous standard for safety testing of SPD’s.

In this section of the paper we will briefly discuss the operation of SPD’s, some common topologies and some key performance criteria for the selection of SPD’s.

**Operation of Surge Protective Devices**

The most common topology for a SPD is the shunt connection. There are various types of SPD’s including Metal Oxide Varistors (MOV’s), Silicone Avalanche Diodes (SAD’s), Gas Arrestors, Spark Gaps and Triggered Spark Gaps. No one device type is superior to other device types. It is more the case that all of these have advantages and disadvantages and they need to be chosen correctly for the application. The discussion on the advantages and disadvantages of these device types is outside the scope of this paper.

In a shunt application, a surge diverter is installed between the phase and the neutral and between neutral and
earth. SPD’s are normally open circuit but turn on when a higher voltage is applied across the terminals during a transient or a surge. They momentarily create a short circuit to ground to allow the surge energy to divert to the ground instead of going to the load. Lightning surges and other power system transients are very fast (durations of few tens of microseconds) and can have very high amplitudes (many thousands of volts). Therefore, to be effective, SPD’s need to switch on quickly and handle large amounts of energy in a short time. Normally, upstream circuit breakers or fuses do not even get time to trip in the event of the surge diverter activating because of the reaction time of circuit breakers and fuses is much slower.

Figure 16 below shows a SPD connected in a shunt configuration between a phase & neutral. Depending on the power system, this connection may be between phase and ground and sometimes between ground and neutral.

A useful but less common topology for an SPD is series connected SPD’s incorporating a low pass filter. Generally series connected SPD’s have the ability to produce lower voltages at the output. Series connected SPD’s, that have a low pass filter suitable for filtering lightning frequencies can also produce lower voltage rise time or dv/dt, often creating superior performance is to shunt connected SPD’s. Series connected devices inevitably have an inductor which is load current dependent which is one reason these are not used on a widespread basis.

Generally series connected SPD’s with low pass filtering are suitable to for mission critical applications or in very high lightning event zones of the world. Figure 17 shows the typical operation of a series connected SPD with low pass filtering.

**Key Performance Parameters of a SPD**

There are various performance measurements that are named in the specification sheets or nameplates of SPD’s.

This section will discuss and explain the 5 of the key performance yardsticks that one can use in making the appropriate selection of SPD’s. These are detailed in the IEC, IEEE and UL standards referred to in this paper.

These are:

- Maximum Discharge Current, or $I_{\text{max}}$
- Nominal Discharge Current or $I_n$
- Maximum Impulse Current, or $I_{\text{imp}}$
- Voltage Protection Level, or $U_p$ or $V_p$
- Maximum Continuous Operating Voltage, or $U_c$

**Maximum Discharge Current, or $I_{\text{max}}$** - The $I_{\text{max}}$ gives an indication of the amount of surge energy the SPD
Nominal Discharge Current or In - In is an indication of the nominal current that the device will need to conduct in its lifetime. The IEC standards require SPD’s tested for common power system applications or Class II applications, to withstand 15 impulses at In followed by 10%, 25%, 50%, 75% and 100% of Imax followed by another In. Cooling between the application of the test wave-shapes is allowed in accordance with IEC61643 Standards.

Maximum Impulse Current, or Iimp - Iimp rating is also called upon in IEC standards for what it calls Class I devices. Iimp is similar to Imax but the testing occurs using the 10/350µs test waveshape. This wave shape has a larger area under the curve and hence a lot more energy. A device with a certain Imax rating will have a much lower Iimp rating. This test wave shape is not used in IEEE and UL standards.

Voltage Protection Level, Vp or Up - The Up characterizes the performance of a SPD in limiting the voltage. The Vp or Up indicates how well the SPD clamps an applied surge. A SPD with a lower Vp or Up, is a better device in terms of limiting the voltage across equipment.

Continuous Operating Voltage, or Uc - SPD’s are voltage-limiting devices and it is important to select a SPD that will not attempt to clamp slight over voltages at 50-60 Hz. Uc is a guide to how rugged the SPD is against over voltages. If the SPD attempts to clamps the voltage continuously, then this can either result in damage to the SPD or even cause a fire hazard if the SPD gets hot.

B. DC Surge Protection

Traditionally, cellular radio antennas were connected to base station radio equipment using coaxial feeders. Microwave radio antennas were either connected with waveguides or coaxial cables (which herein will collectively be called “feeders”). The feeders would carry the baseband frequency and the RF signal. RF feeders have served the industry extremely well. However, as the frequency and the bandwidth transmitted increased, the losses in the feeder and connectors became more significant. There is a limitation on the length of the RF feeder before losses become intolerable and the error rate significant.

The next generation of microwave radio equipment utilized remote radio units close to the antennas which would convert the frequencies to an intermediate frequency. This could be transmitted more efficiently on smaller coax feeders with losses being less of a problem. This method is more common with microwave radio than cellular.

Modern cellular and microwave equipment utilize a remote radio unit (RRU) or a remote radio head (RRH) which is fed from the base station via optical fiber. This eliminates the loss issues on feeders and allows transmission to occur at much higher frequencies with larger bandwidth. Power to the RRU cannot be transferred from the base station to RRU or RRH via the optical fiber. Hence, power is fed separately as DC on copper cables. The copper cables are either separate from the fiber or are a composite fiber-copper cable.

The DC feed acts as a source of lightning surges back into the equipment room. In the traditional radio settings of the past, damage to equipment would normally have been limited to the radio equipment. However in modern scenario damage can occur to the rectifiers or the whole DC power system which would jeopardize other equipment installed at the site.

The need for DC surge protection has been heightened by this development. This issue is covered in more details in a separate technical paper presented by the same author at this conference. The paper will look at

- Location of DC SPD’s
- Sizing of DC SPD’s
- Testing Method of DC SPD’s
- Standards for DC Surge Protection of RRU.

4. SURGE PROTECTION OF TELEPHONE LINES & RF FEEDERS

Surges and transients caused by lightning can couple to telephone lines and RF feeders via magnetic or capacitive coupling. Where telephone lines run parallel to power lines for longer distances, the surges and transients can also couple to the lines through electrical induction.

Leaving these communication lines unprotected may still leave the facility open to potential damage even if other elements of this plan are implemented.
A. Telephone Line Surges

The telecoms services considered in this paper are transported on twisted pair. These may be telephone lines or services like CAT 5 and CAT 6. Each service has two wires, or lines, sometimes called the ‘a’ and ‘b’ wires.

Surges can thus occur from each line to ground, known as L-G or common mode, or occur across the lines, known as L-L or differential mode.

The surges that occur from each line to ground, usually do so at the same magnitude at the same time, hence the name common mode. This is an important observation and derives from the fact that these twisted pairs are balanced, and hence noise signals or surge energy is coupled onto both wires equally. The receiving telecommunications equipment is looking for differential signals, and is most sensitive to noise and surges in the differential mode. That is, the telecoms equipment is generally more robust against common mode L-G signals. The following diagram illustrates the idea of a common mode surge.

![Figure 18: Common Mode Surges & Transients](image)

Generally, a gas arrester only protection is usually sufficient for L-G protection.

![Figure 19: Gas Arrester Device Suitable for Common Mode Transients](image)

Surges on balanced pairs usually start out as common mode. Telecoms equipment is usually robust enough to withstand these signals. Problems can arise however that convert these common mode signals to differential mode. If one wire in the pair actually breaks down to ground either through insulation failure or insufficient clearance at a connection point, that wire drops to ground potential, while the other pair remains at high voltage potential. A large voltage then appears across the line, converting what was a common mode (L-G on each line) surge into a damaging differential mode (L-L) surge.

In a similar manner, surge protection components applied from each line to ground must operate at the same time and behave in the same way. If the surge protection component on the ‘a’ wire operated before the surge protection component on the ‘b’ wire, then the common mode signal would be converted to a differential signal for the time period between both surge protection components operating. This phenomenon is worse when independent components are used, such as two independent gas arresters. To try to minimize this problem, most protectors use a three terminal gas arrester. However, the problem is not completely eliminated as many suppose. The oscilloscope display in Figure 20 indicates this.

![Figure 20: Oscilloscope Display Showing Differential Mode](image)

In this test, an equal impulse is applied from L-G on both leads of a three terminal gas arrester. The lower, left hand side trace shows this impulse on a scale of 1us per division, where the absolute peak of this impulse is around 700V (all traces are 200V per division). The lower, central, two traces show the voltage on each of the leads of the gas arrester. Both are climbing equally, until at around 600V one half of the gas arrester fires, rapidly reducing the voltage on that lead. However, the other continues to climb until around 700V until it fires. The top central waveform shows the difference between these waveforms – it is a pulse of around 600V, resulting in the damaging L-L, or differential mode!
So, to summarize this, the following points need to be understood:

Differential, or L-L, surges are most damaging. L-G surges can get converted to damaging L-L surges.

The following diagram illustrates an L-L surge.

Devices that are suited for handling of differential mode transients will have some second stage surge protective devices like diodes, as shown in Figure 22 below.

As a minimum the coaxial feeders should be grounded at the top of the telecom tower, at the point that they bend close to the ground and at the point of entry to the equipment room or cabinet. The feeder tray shall be kept continuous in its trajectory along the tower. The feeder tray shall be continuous when it leaves the tower towards the equipment room or cabinet, preferably using a curved section as shown in Figure 23. Bonding shall be made on two sides as shown in Figure 24.

Where additional precaution is desirable, coaxial surge protectors with appropriate connector type, bandwidth and surge ratings can be installed at the point of entry to the equipment building or the cabinet.

5. DIRECT STRIKE LIGHTNING PROTECTION

A. Need for Protection

Protection against direct strike effects of lightning protection is a critical consideration for telecommunications towers because of their relative height.

Of late there is increased use of electronics which are installed on the tower mainly in form of remote radio units for cellular and other radio communications. This has led to further consideration for lightning protection on telecom towers.
There are extensive amounts of electronics at all telecommunications sites including those without telecommunication towers. Some of these facilities may have a need for lightning protection as well, for example, central offices, data centers and satellite stations.

B. Recommendation on Protection System for Towers

ITU K56 – Protection of Radio Base Stations from lightning strikes proposes a lightning protection as shown in Figure 9.

Under Clause 6.1 of ITU K56 recommendation, a lightning air termination is recommended on radio towers. However there is no requirement under this standard for lightning down-conductors on metallic towers. There are many existing practices and situations whereby down-conductors are used by tower companies and telecom operators. This will be discussed later.

C. Bonding Essential Part of this LPS Scheme

Bonding is an essential part of the lightning protection system. In summary the following parts of the facility need to be bonded as per recommendations:

- Coaxial Feeders
- Cable Trays
- Tower Members
- Tower legs
- Shielded Cables
- Other feeder cables
- Fence Post
- Reinforcement steel
- AC & DC Power Systems
- Equipment in Shelters & Cabinets
- Remote Radio Units
- Structural Steel
- Indoor and Outdoor mounted ground bars
- Main Distribution Frames
- Incoming Services
- Incoming power and communication lines
- Water pipes

D. Shielding

The telecommunications tower and the cable tray provide significant shielding to feeder cables that are running up the tower.

E. Tower Lightning Protection Systems Utilizing Dedicated Bare Down Conductors.

As aforementioned, existing practices within telecommunication operators may involve the use of a dedicated bare down-conductor. These down-conductors have no real benefit except as a known path to earth in instances when there is uncertainty about conductivity via joints in a tower. This may be due to use of an aged tower or if there is special coating on the tower.

Since the practice already exists in the industry this paper will discuss types of conductors used as bare conductors:

i. Copper Tape - Generally 25 x 3 mm copper tape is used on one or more legs of the tower.

ii. Bare Copper Cable - The size of these should be greater than 50 mm2. PVC insulated cables are rated for low voltage and are not recommended. Any conduction of lightning will cause insulation damage.

iii. Copper Bonded Steel Conductor - Due to high incidence of copper thefts, either solid copper bonded steel or stranded copper coated steel conductors are being used more commonly, in theft prone areas.

iv. Aluminum Bare Cable - The use of aluminum cables is rare in this application however the use of this is seen in theft prone areas.

v. Galvanized steel tape - This is quite a common alternative to copper tape. While this is not as conductive as copper, it does not offer any risk of galvanic corrosion on galvanized steel tower.

F. Tower Lightning Protection Using Isolated Lightning Rods and Down-conductor

In lightning protection there are two ways of mitigating side flashing and flash over risk. One is using bonding and the second is isolation. Since it is very difficult to achieve isolation, bonding has been a more common method.

Isolated systems may offer benefits on towers that have remote radio heads or where the cable or feeder tray is placed close to one leg.

In the case of tower mounted remote radio heads, the isolated system can be used to bypass the lightning energy and dissipate into the tower leg some distance down from the radio heads. In the case of towers where the cable tray is on or close to one leg, the isolated systems can be used on an opposite leg. These systems cannot mitigate all risks associated with lightning and secondary effects like magnetic coupling will still occur.

Figure 25 shows a typical upper termination arrangement. The lightning air terminal is mounted on a 2-3 meter tall fiber glass mast and isolated from the tower. The isolated down-conductor would run some distance (say 15m/45 ft.) down the tower and then connect to a tower leg.
G. BUILDINGS REQUIRING LIGHTNING PROTECTION

There may be a need for lightning protection on mission critical telecommunication facilities like the central office, data centers and major repeater sites.

The types of system available for providing lightning protection to a building are following:

- Conventional Lightning protection installed to NFPA® 780 standard utilizing smooth weave cable system
- Conventional lightning installed to IEC62305 utilizing a variety of conductors including 25mm x 3mm copper tape
- ESE, or Early Streamer Emission System
- Proprietary systems like ERICO® Dynasphere.
6. CONCLUSION

The information presented in this paper is derived from the authors experience and established sources including ITU, IEEE and IEC standards and recommendations.

Attempt has been made to present the concept of the design of lightning protection, noise control and the grounding system at a telecommunication facility in a single document. Designers will need to refer to other referenced documents for more detail when designing or may contact the author for added direction and guidance.

The following 5 parts of the design of the protection system at a telecommunication facility have been discussed:

1. Indoor grounding arrangement
2. Outdoor grounding arrangement
3. AC Surge Protection for incoming power and DC surge protection for tower mounted radio units.
4. Surge Protection & grounding of telephone lines and RF feeders.
5. Direct Strike Lightning protection

It is hoped that this paper provides the reader with a methodical approach to the design of protection systems in telecommunications.

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