LIGHTNING PROTECTION
for RADIO COMMUNICATION SITES

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Abstract - *Radio communication sites are particularly prone to lightning strikes which can cause damage and downtime to sensitive electronic communications equipment. This paper examines the reasons for this phenomenon and discusses protection techniques which may be applied to all radio communication sites whether used as microwave repeaters, cellular telephone basestations for analogue or digital GSM applications or for broadcasting purposes.*
By following a total systems approach it is possible to protect these sites from even direct strikes to towers, antennas and power lines.

INTRODUCTION

It is not difficult to understand why radio communications stations are so prone to lightning strikes. Sites are generally located on elevated ground and mountain tops and have an antenna tower or mast prominently located to optimize radio coverage to the surrounding areas. The tower and its antennas are therefore highly susceptible to receiving direct lightning strikes.

In addition to direct strikes to transmitting structures, direct and induced lightning strikes to power lines feeding equipment buildings must also be considered.

STRIKE INCIDENCE

There are two common statistics used to measure the incidence of lightning strikes. The first is the term "thunderday". This term is defined as a calendar day during which thunder is heard at a given location. The international definition of lightning activity is given as the number of thunderdays per year. This is also called the "isoceraunic level".

Thunderday maps are published by meteorological organizations worldwide. As may be expected the number of thunderdays is generally greatest in tropical regions around the equator and falls off as one progresses north and south towards the poles.

Another commonly used statistic to record lightning activity is the "Lightning flash density". This is defined as the number of lightning flashes to ground occurring on or
over unit area in unit time. This is commonly expressed as per square kilometer per year (km^{-2} $year^{-1}$).

As may be expected there is a relationship between thunderdays and ground flash density. Figure 1, reproduced from BS6651 shows this relationship.

Thunderdays per year	Mean flash density per km^2 per year
5	0.2
10	0.5
20	1.1
30	1.9
50	3.7
80	6.9
100	9
150	15
180	19
200	22

Fig 1. Thunderdays vs. Ground flash density

To assess the susceptibility of the antenna structure to lightning, the number of likely strikes per annum can be readily calculated. The attractive radius of tall, slender structures typical of antenna towers can be found by use of an equation for R_a given by Ericsson in reference 3.

$$R_a = I^{0.64} \times h^{(0.66 + 2I \times 0.0001)}$$

where

R_a = the attractive radius for the structure, in meters

I = the prospective lightning stroke current amplitude, in kiloamperes
h = the structure height, in meters

Using the above equation, a structure with a height of 30m and a prospective lightning stroke current of 130KA, which accounts for 99% of all lightning strikes has an attractive radius of 309m.

The collection area is then given by:

$$A_c = \pi \times R_a^2 \times 10^{-6}$$

where

A_c = the collection area for the structure, in square kilometers.

A 30m high transmitting mast will have a collection area of 0.300 km^2.

Finally the prospective number of strikes per annum can be calculated from:

$$P = A_c \times N_g$$

where
P = the prospective number of strikes per annum
N_g = the ground flash density km^{-2} year^{-1}

In an area with 150 thunderdays, which is typical of Malaysia the mean ground flash density is 15. So a 30m high antenna tower will receive on average 4.5 direct strikes every year.

This is a statistical calculation but provides ample evidence of the need for effective lightning protection at these sites.

THE LIGHTNING STRIKE

The transient discharge of electric current that occurs between a negative charge centre and a positively charged region is a lightning flash. A typical flash is made up of one or more discharge components or pulses, with each pulse consisting of a negative leader stroke and a positive return stroke.

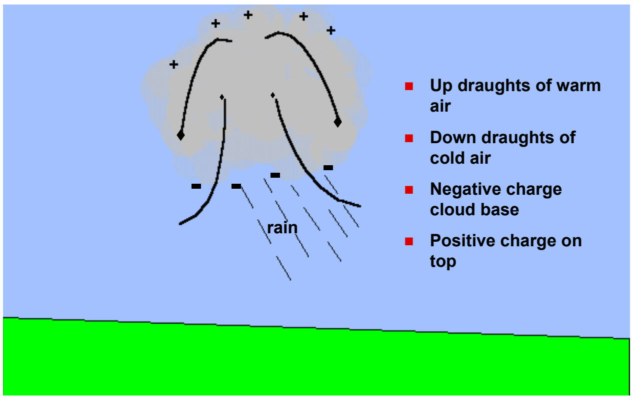

Fig 2. Charge build up

On a normal fine, sunny day the earth has a slight negative polarity, and the electric field so created is about 300V per meter. As a thunder cloud forms, separation of electric charge in the cloud creates a surplus of negative charge in the base of the cloud and over a period of many minutes this will build up to create an electric field in the order of 10KV per meter. Imagine the electric field as essentially horizontal lines in figure 2.

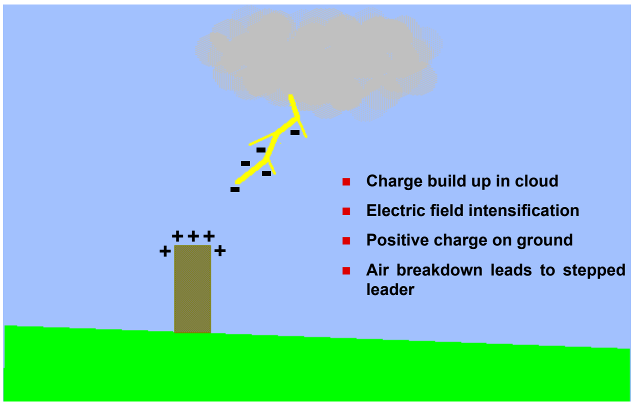

Fig 3. Development of the downward leader

Charge build up continues until the electric field is so great that ionization of the air occurs. As ionization occurs, the stepped leader extends from the cloud towards ground bringing electric charge with it.

Figure 3 shows a building or other structure. The effect of this structure is to distort the electric field as it top is at earth potential. The field lines now must curl around the building, creating field intensification at the top and corners.

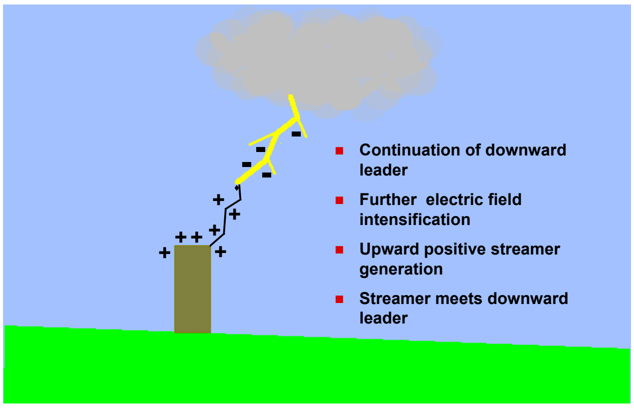

Fig 4. Development of the upward streamer

As the leader approaches ground, the electric field builds up further and field intensification occurs around those objects above ground level. The degree of field intensification depends upon the height of the structure or object.

At some point the breakdown electric strength of air will be reached and ionization will occur. This gives rise to an "upward streamer" which heads up to meet the downward leader.

For tall structures streamer creation is most likely around points of high field intensification, i.e. at the tops of antenna towers and masts and the corners and other extremities of buildings.

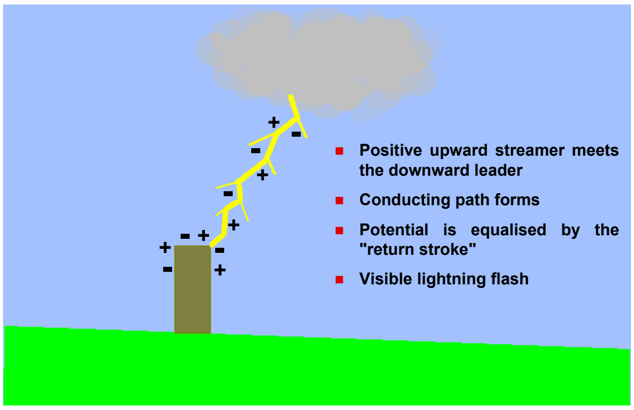

Fig 5. The return stroke

One of the upward streamers will meet the downward leader and complete the ionization path. The electric charge is then discharged via this path and the so called "return stroke" current flows. The return stroke current flow collapses the electric field and it is this collapse in electric field that is responsible induced voltages in power and other metallic conductors.

Thus the structure must be protected against direct strikes plus the indirect effects of a nearby strike creating induction due to the collapsing electric field after the lightning flash.

PROTECTION PRINCIPLES

Direct Strike

When lightning strikes a tower that is grounded the current pulse, which typically may have a rise time of 1 microsecond and a decay to half amplitude of 50 microseconds, will flow down the tower to ground.

It is important to be aware that no matter what form the lightning protection takes there will be a potential gradient developed up the tower. This potential is essentially caused by the self inductance of the tower. Block in ref. 6 presents a formula for approximating the inductance of a typical slender tower. The self inductance of a 30m tower is 25 microhenries.

The potential at the top of the tower may be calculated from the following formula:

$$V = L \times dI/dt$$

where

L = Self inductance in microhenries
dI/dt = Rate of rise of current in amps per microsecond

For a 50KA current rising in 1 microsecond, the potential at the top of the tower will be approximately 1.25MV.

It is not possible to reduce this voltage build up. Any protection system must take this into account.

Earth Potential Rise

As the current pulse flows to ground a rise in ground potential will also occur. By ignoring the effects of inductance and considering resistance of the earthing system alone this earth potential rise can be easily calculated.

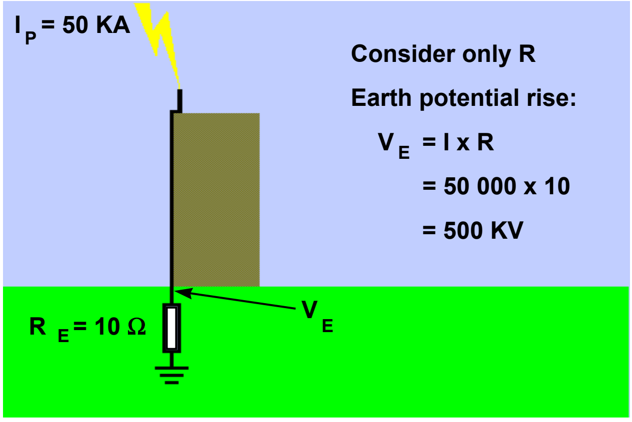

Figure 6. Earth potential rise

For example a 50KA impulse flowing to ground with a 10 ohm earth resistance will raise the earth potential by 500KV as figure 6 shows.

Since the local ground potential rises, any cables leaving the vicinity of the tower will carry this potential to the transmitter building. Current will flow along coaxial cable sheaths and create a potential between the inner and outer conductors of these cables.

At many stations the tower can often be located some distance from the equipment building so it cannot even be assumed that both the tower and building earth will rise to the same potential.

Surge Protection

Whether the tower is struck by lightning or lightning strikes the incoming power line, surge protection on all incoming services is essential. The aim is to reference all incoming services to the local ground either directly or via surge diverting components such as surge diverters, power surge filters, coaxial cable protectors etc.

DIRECT STRIKE PROTECTION

A direct strike to an antenna tower is unlikely to damage antennas unless the antenna itself is struck or correct earthing and bonding principles have not been adhered to.

Antennas which form the highest point of the structure and are not at tower potential are particularly vulnerable and it is difficult to protect these effectively. High gain whip antennas mounted at tower top are typical examples. The best form of protection is to carry some spares.

Where antennas are mounted on the lower faces of the tower, it is usual to erect a vertical spike, or Franklin rod, at the top of the tower to act as the air terminal. To be effective the top of the rod needs to be at least 3 meters above the highest point of the antenna.

No special precautions with regard to downconductors on all steel towers are necessary. The four legs of a self supporting tower provide an excellent path for the lightning impulse current. Special air terminals and proprietary downconductors consisting of custom made coaxial cables etc. are totally unnecessary. They do nothing to reduce the potential rise at the top of the tower and cannot possibly be insulated to the level required to prevent flashover to the tower itself.

Concrete towers and masts can utilize the concrete reinforcing, ladder and any other steel work for the downconductor path. Figure 7 shows a typical GSM site with concrete mast. Note the lightning air terminal projecting above the antennas. This air terminal is not high enough and provides insufficient cover to prevent a direct strike to the antennas.

Figure 7. GSM antenna structure. Note lightning finial is of insufficient height.

EARTHING AND BONDING

Since a direct strike to the tower will raise earth potentials and cause current to flow in feeders and coaxial cable sheaths, it is essential to pay particular attention to correct earthing and bonding practices.

1. Ensure that the antenna system is securely bonded to the tower structure.

2. Bond the sheath of the feeder cable to the tower structure at the antenna.

3. Bond the sheath of the coaxial feeder to the tower structure at the point where it leaves the tower. Do this just prior to the bend in the feeder. This will divert current on the feeders to ground.

4. Ensure that the tower is securely earthed. For a 50KA lightning impulse every one ohm reduction in earth resistance will reduce the earth potential rise by 50KV.

5. Bond the sheath of the cable to the station ground at the point of entry to the equipment building.

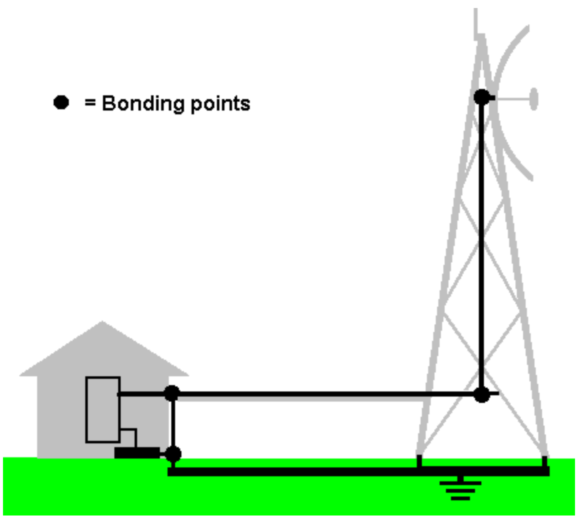

Figure 8. Earthing and bonding points

Figures 8 shows the principle of earthing and bonding to create a common earth with single point earthing in the building and bonding of tower and building earths. Figures 9 and 10 show cable sheath bonding at a typical GSM site.

Figure 9. Cable sheath bonding at the base of the tower

Figure 10. Cable sheath bonding at the building point of entry

BUILDING LAYOUT

The geometry of the interconnections in and around the building are of vital significance to the effectiveness of the lightning protection system. The objective is to provide a path for the potentially destructive lightning current flowing from the antenna to the AC supply line via a path that does not include the interior of the building.

The ideal building layout would be one where the coaxial feeders, AC supply and other services enter the building at one point. At this point all services are connected to the building ground either directly in the case of coaxial cable sheaths, water pipes etc. or via surge protection devices in the case of AC power, telephone, coaxial feeders etc.

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It is impossible to reduce earth resistance to zero so there will always be earth potential rises developed when lightning strikes. By carrying out the above procedures a single earth will be produced such that an equipotential earth rise will occur and current flow in the building through vital equipment will be eliminated.

SURGE PROTECTION

AC Power

The AC supply line to the building usually represents the lowest impedance to remote grounds and will therefore carry much of the lightning current flowing away from the site. The surge protection installed must thus have sufficient capacity to carry these currents.

This situation is altogether different from the case of induced voltages in power lines for which many surge protection devices are designed.

It is usual to choose mains power filters in preference to shunt connected surge diverters. The filters provide multistage protection and redundancy in the event of a component failure. In addition their let through voltage is low enough to protect the most sensitive electronic equipment. Shunt connected surge diverters are not. Figure 11 shows the configuration of a typical mains power filter.

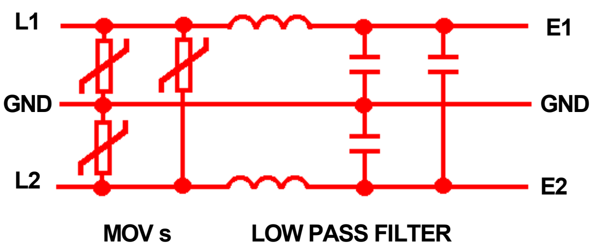

Fig 11. Mains power filter

Generally three phase versions with surge ratings no less that 120KA would be employed. Current ratings depend upon the station requirement. For typical cellular GSM sites this would be in the order of 40A plus per phase. These filters are installed at the building point of entry of the AC power supply. Figure 12 shows a typical power surge filter with 63A three phase rating.

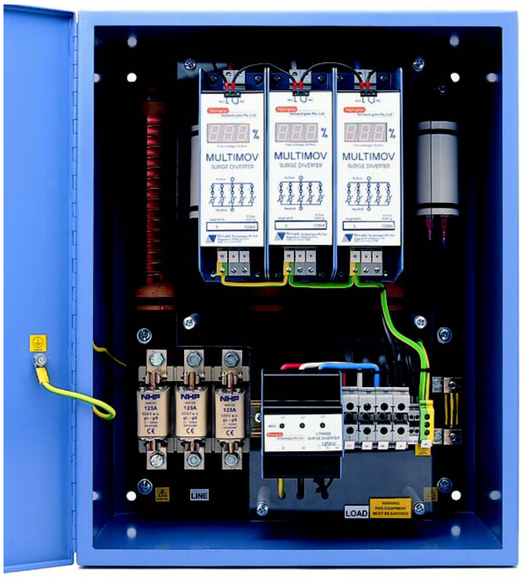

Figure 12. Power Surge Filter 63A three phase

Coaxial Cable Protection

At high frequencies the components used in power filters are unusable. Metal oxide varistors have a high self capacitance which shunt RF energy. The only useable device is the gas filled arrester which may be connected between the inner and outer sheaths of coaxial cables to clamp differential voltages.

Such devices are readily available for low power transmitting and receiving equipment up to a few hundred watts.

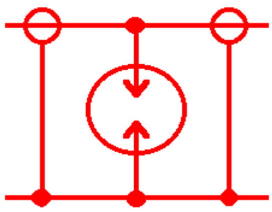

Fig 13. Gas arrester coaxial protector

When lightning strikes a communications tower the potential at the top of the tower rises. This has already been established. Antennas located at the top of these towers must also be subjected to these potential rises. Antennas that are fed with coaxial cables must have their inner and outer conductors both subjected to these potential rises.

At the building entry the lightning energy can be diverted to earth by the action of bonding the coaxial feeds to earth. Figure 10 shows this. The inner conductor of these cables must also be protected. This is done by coaxial surge protectors which divert energy from the inner conductor to earth. A recommended procedure is to establish a station earth bar then utilize bulkhead mount coaxial protectors mounted on this earth bar to provide the termination point for incoming coaxial feeders. Figure 14 shows an actual example of an earth bar with earthing conductors terminating and coaxial surge protectors mounted on the bar. The figure shows two protected cables and a spare coaxial feeder also protected.

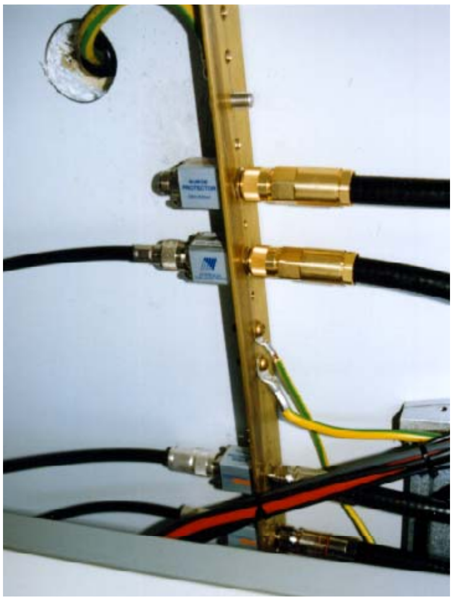

Fig 14. Station earth bar with coaxial surge protectors fitted

These coaxial cable protectors are installed at the building point of entry.

For cellular telephone sites there are two specific cases to be considered.

(a) The protection of cellular antennas requires special attention. Gas arrester type surge protectors, as described above are not recommended. Instead quarter wave stub type surge barriers are to be preferred. They offer superior performance in terms of let through voltage and minimal intermodulation. A typical quarter wave stub surge barrier utilising 7/16 DIN type and N type connectors is shown in figure 15.

Quarter wave stub surge barriers are particularly useful on transmitter cables and also offer superior performance on receive antennas. Active receive antennas with power feed up the feeder require gas filled arrester types both at the equipment and head ends.

Fig. 15 Quarter wave stub surge barriers

(b) Link equipment utilising microwave bearers with active head units require special attention. Protection is required at both the head and equipment ends. Attention must be paid to the signals, baseband, IF and power on the interconnecting cables. Novaris can advise on the most suitable form of protection once the signalling parameters are known.

Signal Line Protection

Incoming telephone lines and other services, even the feeds from solar panel power supplies require protection at their point of entry. Typical protection devices that may be utilized include gas arresters and multistage protection in configurations similar to figure 16.

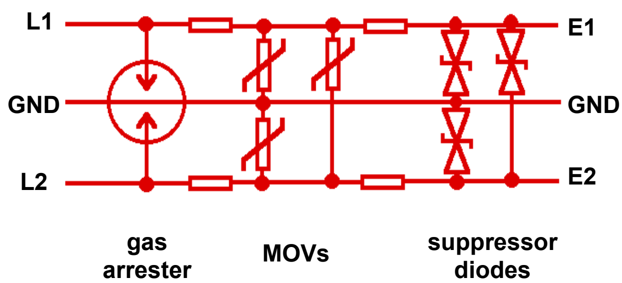

Fig 16. Multistage signal line protector

The principle is that every incoming service must be protected at its point of entry and the protection must be referenced to a common earth point, the station earth bar.

CONCLUSION

The protection from lightning of radio communication sites can be achieved and protection from even direct lightning strikes is possible. The author is familiar with many examples where direct strikes have occurred and full protection has been achieved.

The mechanism of a lightning strike must first be fully understood. It is essential that all factors be fully considered. These include:

- direct strike protection - install lightning finials to prevent direct strike to antennas.
- provide an effective earthing system for the tower - remember the tower itself provides the best downconductor.
- bond coaxial feeders and waveguides at the point where they leave the tower and at their point of entry to the building.
- bond the tower earth to the building earth.
- ensure all services, antenna feeders, power and telephone enter the building at the same side of the building.
- provide power surge filters for the incoming power.
- provide coaxial surge protectors for every incoming coaxial feeder.
- protect every signaling pair with multistage surge protectors.

The only time proven method of lightning protection is to adopt a systematic approach. Lightning protection standards, particularly those revised since 1990, advise on this systematic approach. There are no short cuts and systems which purport to enhance the attraction of lightning, divert lightning, dissipate lightning or prevent lightning should be rejected. There is no solid evidence that such systems actually operate as claimed and all recognised lightning protection standards worldwide reject such systems.

REFERENCES

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__Phillip R Tompson__ graduated from the University of Queensland with an honours degree in Electrical Engineering in 1972. His early experience was gained as a communications engineer with Telecom Australia, then with power utilities specializing in communications and control systems design and management. His work now involves consultancy in the field of lightning protection, power quality as well as product design work for surge and overvoltage protection products. He is a chartered member of IE(Aust), IEE, and IEEE as well as a member of the Australian Standards Committee on lightning protection..