Technical E-Paper

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Antenna design and atmospheric electrical phenomena.

PART ONE: electrical phenomena and antennas.

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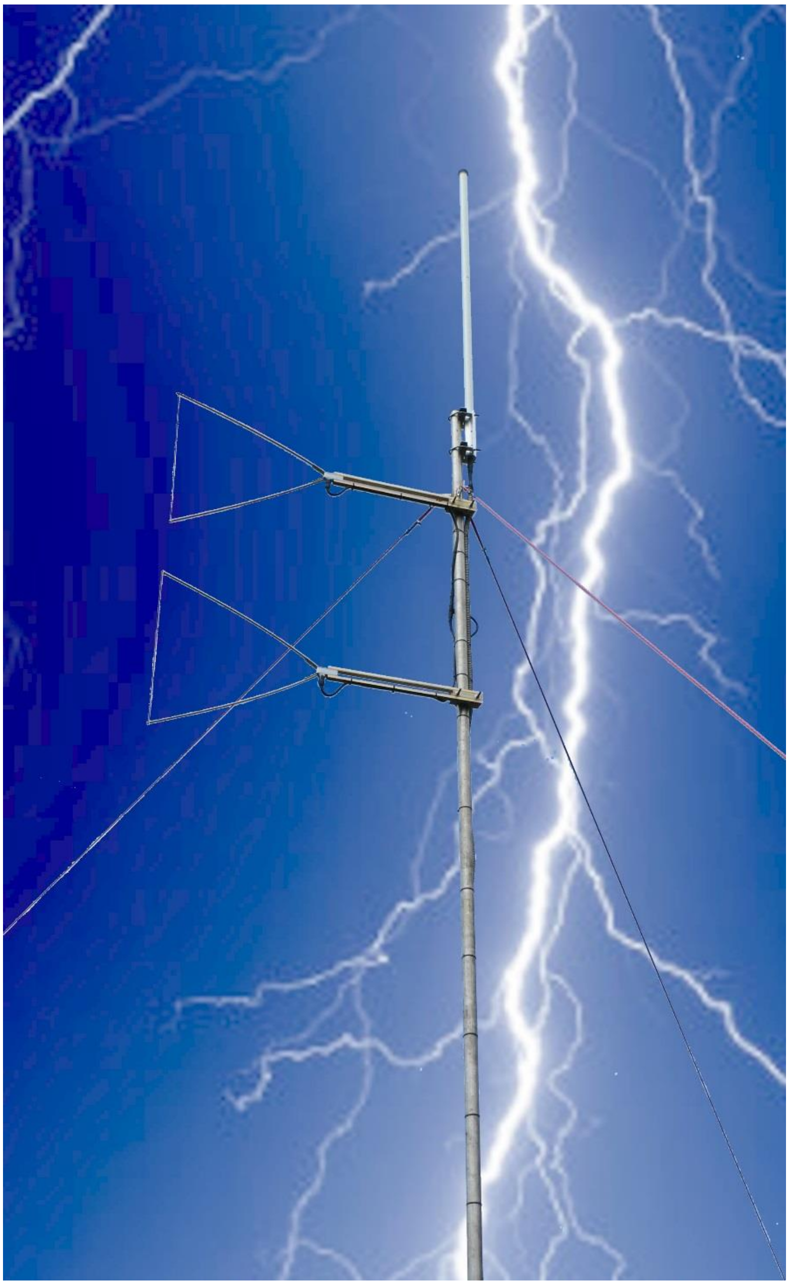
Atmospheric electrical phenomena and their often-devastating effects do not only affect the radiocommunications sector.

Regulations and procedures exist aimed both at identifying protective measures to adopt for people, structures and systems, and at carrying out a correct risk assessment for the purpose of the safety of property and people.

So, as regards antennas and their design, we will present a brief overview of this topic, divided into two parts.

PART ONE:
Which atmospheric electrical phenomena can cause damage to telecommunications systems?

PART TWO:
What protective devices can be used in an antenna system and/or in an antenna itself?



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1. Introduction.

In a radiocommunication system, the antenna is almost always installed in a position that is free from obstacles and is connected to the receiving and/or transmitting devices through a transmission line.

Most antennas are therefore a potential lightning rod, that is more "effective" when the installation is located in an isolated, elevated area with a potentially high probability of lightning occurrence.

However, if the direct discharge of lightning on an antenna is a destructive event, there are other *indirect atmospheric phenomena* that can more frequently cause failures and malfunctions to the radio equipment connected to it.

Indeed, there are atmospheric phenomena of a non-violent type, i.e., that do not directly affect any object or structure on the ground, but that can represent a hazard for telecommunications systems due to the lightning electromagnetic pulse (LEMP) they radiate.

Furthermore, if the antenna has one or more extended conductors isolated from the ground, there may be a build-up of electrostatic charges on them that can generate a high potential difference at the input connector, with disastrous effects on the semiconductor electronic components of the devices connected to it.

There is a highly complex regulation (CEI EN 62305, CEI 81-10) concerning Lightning Protection Systems drawn up by the *International Electrotechnical Commission (IEC)* which includes numerous standards regarding the protection of buildings and electronic systems as well as lightning risk assessment.

It would be impossible to deal with this topic exhaustively and so here we will discuss it only in relation to antenna design and the precautions adopted by manufacturers to limit damage caused by electrical phenomena.

This article, as always written with the intent of giving a direct and operational overview of the subject, could therefore be a useful starting point for whoever needs to purchase an antenna for a specific application or, better still, to inform technicians who have to define the specifications of a custom antenna made to measure for a specific application.

2. Electrical phenomena and antennas.

From a practical point of view, the electrical phenomena that can jeopardize the integrity of the antennas and/or the radio equipment connected to them can be of three types:

- Direct lightning strike;
- Lightning electromagnetic pulse (*LEMP*), following indirect lightning events;
- The build-up of electrostatic charges on the antenna conductors.

While the first event is usually harmful for the antenna itself, the other two can cause faults in the equipment, above all if no particular precautions are adopted.

2.1. Direct lightning strike.

This event, of a violent and destructive nature, occurs when lightning strikes the ground and directly strikes the tower, pylon or support on which the antenna is mounted.

In Italy, there are around 600,000 lightning strikes every year, the occurrence of which (average number of lightning strikes per km^2 per year, or *the ground flash density Ng*) largely depends on the geographical conformation of the territory. In this regard, there are updated maps that can offer an initial assessment of the occurrence of the phenomenon, monitored thanks to the SIRF system or *CESI* 's *Italian Lightning Detection System* (*www.fulmini.it* website).

The origin of lightning.

Lightning occurs in the presence of thunderstorms, where warm and humid air masses rise upwards, exploiting different physical mechanisms. The separation of the electric charges takes place in this context and, through processes such as friction and nebulization, the drops of water and ice crystals become electrostatically charged.

This charge separation affects different areas of the storm cell: particles with a positive charge build up in the upper part of the cloud, while those with a negative charge prevail in the lower part; finally, a small area of positive charges forms at the base of the cloud due to the corona effect caused by spires on infrastructures (plants or buildings) present on the ground.

With increasing charge separation, field strengths of hundreds of *kV/m* can be reached locally, sufficient to create ionized paths that precede the actual lightning strike.

Whenever lightning strikes the ground, there is an immediate transfer of charge which causes a compensation of the potential difference between the clouds and the ground. Two types of lightning can thus be created, *descending lightning* (cloud-ground) or *ascending lightning* (ground-cloud) depending on whether the ionized paths are directed downwards or vice versa.

Descending lightning is most frequently negative and the ionized channel preceding the main discharge descends almost to the ground. In this circumstance, a strong electric field gradient is created near the protruding and/or spire structures present on the ground, and the main discharge is triggered.

Ascending lightning (ground-cloud) may occur if there are objects of considerable height on the ground such as radio antenna towers, wind turbines, bell towers, etc. In this case, the corona effect, which causes a distortion of the electric field (increase in the charge density) on the pointed tops of these structures, triggers a stepped leader directed towards the cloud. Contrary to descending lightning, ascending lightning can occur with equal occurrence with both positive and negative polarity.

Lightning current.

Without going into further detail about the physical mechanisms that lead to the creation of lightning, the energy discharged by it to the ground or on the structure struck is enormous, and typically varies between 10 and 200 kA, with a total charge transfer of 5 $\div$ 10 C concentrated in a very short time interval.

The nature of the discharge, whether impulse (short lightning strike, lasting a few tens of μs) or longer lasting (long lightning strike, lasting a few hundred *ms*), in any case releases a huge amount of energy, causing heating (and often fusion) due to the Joule effect of the conductors crossed by the lightning current. In this regard, it is possible to carry out a more in-depth analysis of the electrical quantities involved, but this is beyond the scope of this article.

An antenna struck by lightning.

If, instead, we consider how an antenna is built, it consists of one or more metal radiating elements connected to the input section either directly or through a power, distribution and/or adaptation line. An antenna is therefore a set of conductors, connected more or less directly to the ground.

Unless we are dealing with large systems operating in rather low frequency bands (MF/HF), in which the radiating elements and/or transmission lines have a considerable section (**Figure 2.1**), an antenna struck by lightning usually does not survive the discharge.

Let's consider, for example, a common GSM/UMTS mobile radio panel made of radiating and circuit elements that are unable to withstand strong currents. In these installations, lightning usually strikes a part of the structure (tower or pylon) and propagates towards the ground following the path with least impedance. There is therefore the protection offered by the tower itself and by the integrated lightning rod and earthing system.

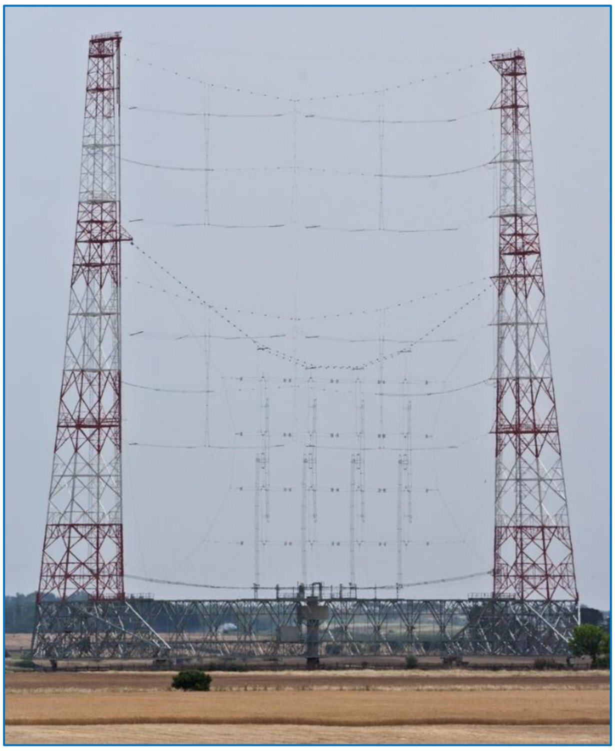

Figure 2.1
Short-wave rotating antenna of Vatican Radio, at the the S. Maria di Galeria station near Bracciano.

It follows that the protection devices used in most antennas are effective and necessary to prevent two other types of electrical phenomena, which we will now describe.

2.2. Lightning electromagnetic pulse (*LEMP*).

During a storm, there may be other more indirect and distant events, such as cloud-to-cloud lightning, that represent a serious danger for electrical and electronic systems due to the lightning electromagnetic pulses (LEMP) they radiate.

This type of disturbance, which we can imagine as a broad-spectrum radio signal similar to those generated by an old spark-gap transmitter, even if extremely more powerful, generates impulse type overvoltage which, although not destructive for the antenna itself, can produce major failures at the connected equipment.

In this case, the regulation is based on the concept of *lightning protection zones*, for which all possible inputs of the overvoltage are considered, not least the power supply network of the system, with various countermeasures aimed at isolating the electronic systems from any external influences.

In our case, focusing on antennas, construction measures have to be adopted, both inside and/or outside the antenna itself, aimed at preventing any overvoltage caused by a LEMP event from propagating through the power supply line (generally a coaxial cable) to the input connector of the device.

2.3. Electrostatic charge build-up on the antenna conductors.

Every large metal object, isolated from the ground, is potentially subject to an electrostatic charge build up which leads it to have a different potential compared to the ground.

This is primarily due to a terrestrial electric field which, in good weather conditions, is about 100V/m close to the ground and becomes much higher even just a few tens of meters from it. In the case where a sufficiently large conductor (that is, with a certain capacity of its own) is isolated from the ground, this tends to slowly charge itself with respect to the ground and this excess charge is not always promptly eliminated.

In the case of a large antenna formed of one or more insulated conductors, under certain conditions of humidity, wind, dust or snow, or not necessarily in the presence of a nearby storm phenomenon, it is possible to experience a progressive and continuous build-up of an electrostatic charge between the two antenna conductors (for example, a dipole) or between a conductor to earth.

This phenomenon, referred to as *electrostatic charge build-up*, can be compared to what happens in a *Van de Graaf generator* when it is charged, in this case due to the action of a mechanical element (a transmission belt in dielectric material) moved by an electric motor.

Through the transmission line, which in this case also becomes a further capacity parallel to the radiating element, high voltages can therefore occur at the antenna connector: for example, from personal experience, a simple 40-meter HF wire dipole with a 20-metre descent in coaxial cable can generate sparks of a few centimeters if the cable connector is brought close to a conductor connected to ground.

Conclusions for the first part.

So far, we have looked at atmospheric phenomena that can potentially cause damage to electrical and electronic equipment, in particular, to radio communication systems.

In most cases, direct lightning strikes, that discharge high intensity currents towards the ground, cause considerable damage unless there is a protection structure (lightning rod) that *diverts* the path of the discharge along the path with least resistance and inductance, ensuring that antennas and transmission lines are not directly affected.

As regards the antennas and the devices connected to them, these can be protected from events of minor intensity by means of protection devices to be applied near the antenna and/or incorporated in it.

It should be noted that an event that we could call *less intense* can occur following a direct discharge of lightning, for example on a structure (pole or pylon) already protected by a lightning rod or at another place near it, generating a potentially harmful *LEMP* event for all nearby electrical and electronic equipment that is not adequately protected.

Consequently, in addition to the protection of the structure, it is necessary to protect the individual systems using devices which, in our case, concern the antennas.

This topic will be discussed, as always from the point of view of an antenna designer, in *part two* of the article.

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