Lightning
PART 2
PROTECTING AGAINST IT

by Greg Grant

All the early electrical pioneers were fascinated by lightning, none more so than Michael Faraday, who would stand at the window for hours watching the effects and enjoying the scene. However, shortly after Samuel Morse got his eponymous code accepted and the earliest telegraph lines were up and running, attitudes changed markedly. One immediately noticeable problem was that lightning interfered with signals and damaged both lines and terminal equipment.

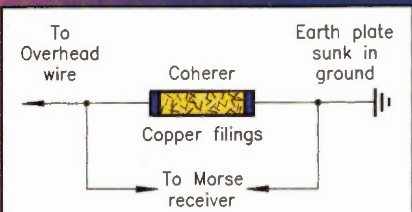


Figure 1. Edouard Branly's Coherer used as a lightning protection device for telegraph equipment.

These early circuits were 'single line' systems, where the earth itself was used as one cable. The overhead wire was connected to earth through the recorder coils, which meant that when it picked up a powerful electrical discharge, the resulting current flowed through these sensitive coils, usually damaging or destroying them.

This remained a problem until 1890, when the French physicist, Edouard Branly, developed the Coherer – see Figure 1. A glass tube filled with metal filings, this device was developed as the earliest receiver for the new experimental vogue of the day, radio waves. A coherer usually had a resistance of several Megohms, but when an electrical discharge occurred close to it, this resistance dropped dramatically to a few hundred ohms.

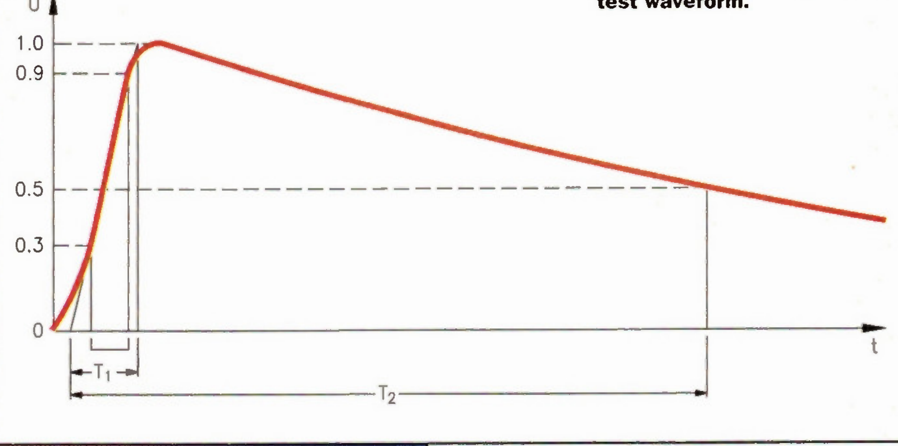
Whilst Branly continued with his radio experiments, others saw his discovery as one way of protecting telegraph lines. The Varley brothers – later famous for their test meters and other indicative devices – devised the circuit below, in which a coherer was placed in parallel with the overhead telegraph wire and the earth plate.

Generally, the coherer's high resistance did not interfere with the efficient operation of the telegraph but, when lightning struck the wire, the coherer became a near-instant good conductor, shorting the potentially damaging current. Thus, the overhead wire acted as an independent lightning conductor.

Another early electrical engineer who was greatly interested in lightning was the radio pioneer, Oliver Lodge, who popularised the coherer in Britain. In 1892, he took lightning protection that little bit further towards scientific enquiry by collecting together the various protective zones provided by a lightning conductor.

The point to remember about lightning is that the problems it creates can vary enormously, from one area of the world to another and from one locality to another within those areas. When it strikes the earth, for example, the potential gradient can exceed 1kV/m at a distance of 100m from the strike. Buildings separated by 100m can have ground potential differences of greater than 20kV. On directly striking an object, lightning is infinitely more dangerous, occasionally generating currents approaching a value of 10^6A for a duration of some 50μs.

Figure 2. The IEC's specified test waveform.



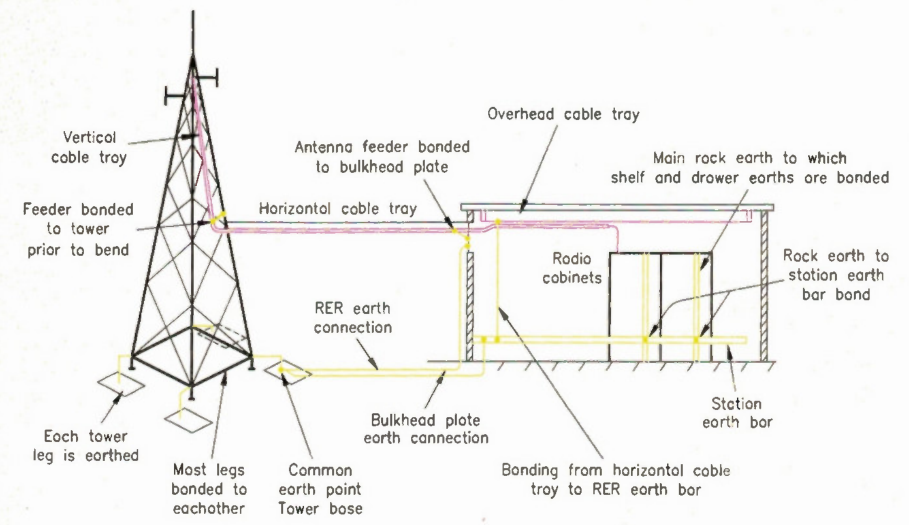


Figure 3. A typical Radio Equipment Room/Antenna Mast location.

Where protection for electronic equipment is concerned, therefore, there are three factors to bear in mind. Firstly, the number of flashes to ground per square kilometre annually; secondly, the earth resistivity reading and finally, the amount of shielding provided by the locality's buildings, power lines, communications cables and the like.

Figure 2, the test waveform of the International Electrotechnical Commission's (IEC) journal 'High Voltage Test Techniques', gives some idea of what the electronics profession in general is up against when lightning strikes.

It illustrates a waveform with an extremely rapid rise time – around 1μs – and frequency components in the Megahertz (MHz) range. Consequently, lightning precautions begin with the antenna mast and the Radio Equipment Room (RER), before considering the equipment itself.

The Equipment Location

The mast/RER location of Figure 3 is typical of many radio sites world-wide. Ironically, ideal conditions for communications equipment are equally as helpful to lightning. Antennas, of course, must have sufficient height to clear any surrounding obstacles, which can also cause problems with lightning.

Frequently, however, some lightning problems can be rectified by changing the antenna's physical location on the mast whilst in other areas, the likelihood of a lightning discharge is so remote that the normal earthing provided by a metal mast is more than sufficient.

Basically, there are two fundamental rules when protecting equipment from lightning strikes: firstly, prevent CURRENT from reaching the equipment and secondly, take precautions against external VOLTAGES.

An antenna tower is a complicated structure. The bonding paths have to make contact between the antennas on the tower and the equipment in the RER. In short, there is a metallic bridle path between the equipment and the tower, perfectly capable of introducing currents – and therefore, potential rises – into the communications equipment.

In Figure 3, the antenna cables are routed down the tower on the vertical cable tray, which bends at the bottom onto a similar horizontal tray, which carries the cables to the building entry point. From here, the cables enter the RER onto another tray, located above the communications system, prior to connection to individual equipment.

Figure 4 illustrates the multiple earth paths for a correctly bonded communications installation, which will divert the discharge currents away from the equipment. The result is a reduction in lightning voltage, brought about by the earth paths from the vertical cable to the horizontal cable tray and that at the RER cable entry point.

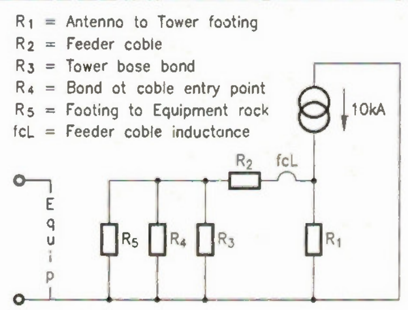


Figure 4. The earth paths of a correctly bonded radio communications installation.

Furthermore, the feeder cable inductance at the vertical-to-horizontal bend, fcL, provides additional series impedance to the lightning current, routing it through the antenna-to-tower footing path, represented by R1. The cable bend should be as close to the designed cable bending radius as possible, the tower bond being made ABOVE the bend. Inductance, however, can create as many problems as it solves, and usually unwittingly.

The majority of series paths use copper strip because of its low resistance and inductance, but a neat and tidy mind, the sort that bends the copper strip fastidiously around the tower structure, can actually re-introduce inductance into the earth path!

The better, not to say far safer, technique is gentle, untidy bends, none of which should be less than 450mm radius, as the potential difference between two points on a copper conductor with a small bend could cause an arc across the loop. Indeed, a hole THROUGH an obstruction is infinitely preferable to a loop around it.

The antenna feeders are earthed to the RER bulkhead plate which, itself, should be EXTERNALLY earthed to one of the tower base's common earth points. The equipment drawers and shelving are individually earthed to each cabinet earth bonding strip which, in turn, is bonded to the power system earth, which is also taken to one of the tower base earth plates, on a SEPARATE lead.

Protection Devices

The Franklin Rod, still much in use today as a glance at almost all church towers and steeples verifies, remained the major lightning protection device until the early years of the present century. However, the increasing use of electric power and the rise of the communications and broadcasting industries, made lightning protection something of a priority and manufacturers realise that new devices were needed.

Consequently, there is a wide variety of equipment available designed to thwart the demon that is lightning, such as voltage-limiting devices, current-interrupting systems, drainage coils, isolation transformers and many more. The following paragraphs give but a brief insight into a near-inexhaustible subject.

The earliest of the 'new' developments was the Zero Field Area, or Field-Free Space, based on an idea first put forward by Michael Faraday. In this concept, the walls of a RER or electronics laboratory are lined with wire netting or metal plating, joined together and efficiently earthed, giving a zero potential enclosure which no electric field can penetrate nor in which one can develop, thus protecting the equipment inside. This Faraday Cage, as the enclosure is termed, is widely used in communications and electronics, particularly in Electromagnetic Compatibility (EMC) testing and in Electromagnetic Pulse Protection laboratories.

By 1927, the Vacuum Gap Protector had been devised as a Lightning Arrester. It was triggered by the voltage developed on the power line by the lightning discharge. Another early protective device was the Air Gap, which used retort carbon for its electrodes, firstly for the material's non-corrosive properties, secondly for its high melting point. Indeed, many Air Gap protection devices are still in use today, world-wide.

The Gas Gap, or Gas Discharge Tube (GDT), was another lightning protection development, although the earliest examples suffered from a number of problems, among which was fragile construction, ineffective sealing and high cost. By the 1960s, however, modern manufacturing techniques had improved GDTs considerably.

Present-day versions, with two gaps enclosed in the same envelope, are very effective as both gaps tend to strike simultaneously. The Striking, or Sparkover, voltage depends on the product of the gas pressure and the electrode spacing. A hydrogen-argon mixture, at low pressure, is usually employed.

In equipment terms, protective devices must limit potential differences to a level where they will not cause damage, yet be rapid-acting. These requirements are usually met by a double protection system, similar to that of Figure 5.

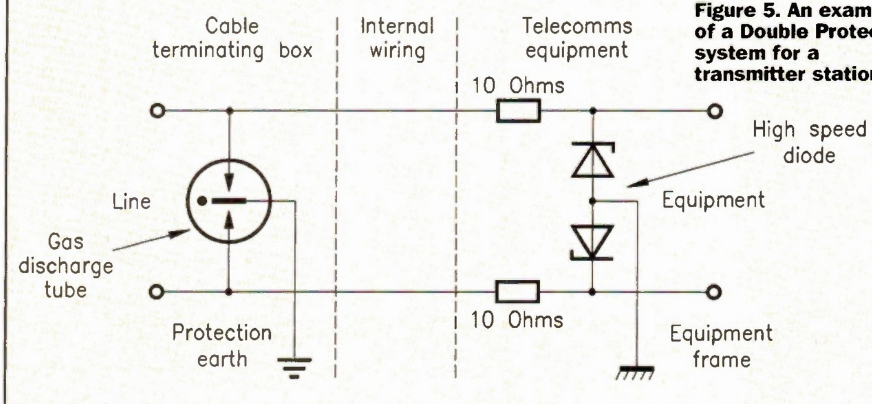


Figure 5. An example of a Double Protection system for a transmitter station.

The GDT clamps the high voltage, high energy surges, whilst the high-speed diode clamps the GDT's striking voltage which, at around 300V, could still cause equipment damage. The resistors isolate the tube from the diode, otherwise the former would not trigger because the diode would clamp the applied voltage to below the tube's triggering potential. This, in turn, would result in the diode taking the total surge current and would probably being destroyed as a result.

GDTs should be visually inspected on a regular basis and certainly before, and after, the winter months in the temperate zones. They should also be replaced bi-annually, as a matter of routine, and their replacement recorded.

Where power lines are concerned, protectors differ in many respects from those used in communications equipment. To begin with, the operating voltages are far higher and the protectors must reflect this. Consequently, Power Surge Arresters are used.

Power Surge arresters are designed to limit the magnitude of transient voltages and Figure 6 illustrates a 30kV, valve-type power station Surge arrester.

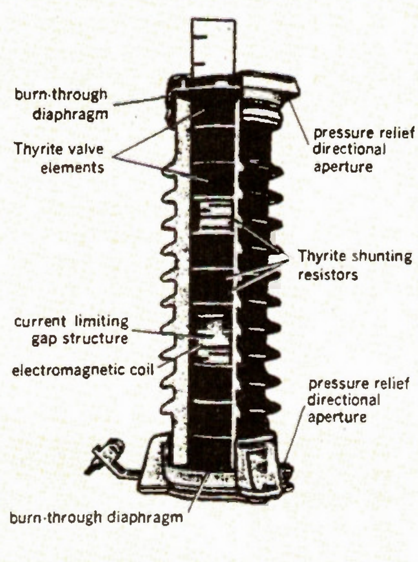


Figure 6. A valve-type power station Surge arrester.

The device consists of a gap structure in series with current-limiting elements. The gaps prevent current flow except when the voltage across the device exceeds the critical gap flashover level.

The current-limiting element is a non-linear resistor, whose resistance decreases considerably as the voltage across it increases. Since the Surge Arrester cannot, obviously, distinguish a lightning discharge from a power generator surge, it attempts to limit ALL abnormal voltages above the Gap Sparkover voltage.

The unit's maximum Transient Voltage Level is determined by the Gap Sparkover voltage and the Discharge Voltage Characteristic. Taken together, they determine the arrester's Protective Efficiency. The Discharge Capability, on the other hand, is a measure of the device's endurance to severe lightning and switching voltages.

Another lightning protection device much used in communications is the Line Barrier, illustrated in Figure 7. Each unit provides isolation protection for two, 2-wire audio landlines, one barrier being used for each transmit channel.

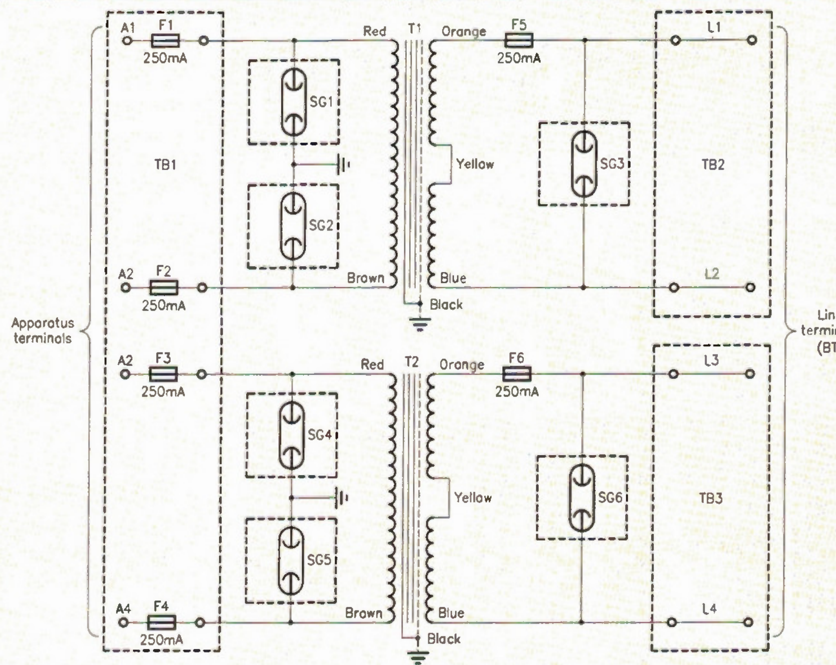


Figure 7. The circuit diagram of a LIne Barrier unit.

When a voltage surge appears across the unit, the Surge Arresters, SG1-6, strike, the resulting current blowing the in-line, 250mA fuse, open-circuiting the line. The line transformers are of the 600Ω, 1:1 type, which introduces an insertion loss of 0·5dB across the audio band between 0·3 and 10kHz, a small price to pay for lightning protection. Each unit, which weighs a substantial 8·5kg, is connected to the transmitting station earth. The removal of this connection renders the unit inoperative.

Finally, there is, perhaps, the most controversial of protection devices, the Radioactive Lightning Preventer. This is based on the Franklin Rod Cone protection principle and utilises a radioactive source, raised above the area or building to be protected.

The radioactive source ionises the air above the building – an air traffic control tower, for example, or a power generating station – the resulting liberated ions greatly increasing the 'effective height' of its mounting pole. Consequently, the protective cone's base radius extends considerably, defending a far larger area than a single Franklin Rod could. However, given the health fears generated by the mere mention of radioactivity, this protective technique is little-used.

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