INFORMATION BOOKLET

LIGHTNING PROTECTION for RADIO TRANSMITTER STATIONS

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LIGHTNING PROTECTION
For
RADIO TRANSMITTER STATIONS

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OVERVIEW

1 Unfortunately, the real-world environment for radio transmitter stations is one where periodic lightning storms occur and cause some finite incidence of antenna and power line strikes. The actual strike incidence will vary widely with general geographic location and is also affected by the local topography, the height of the transmitter mast and the routing of the incoming power lines.

1.1 Unless definite precautions are taken, such strikes can cause transmitter damage, particularly to the final rf amplifier and the ac line rectifiers therein. A superbly reliable transmitter in the laboratory environment could become very vulnerable in the real-world situation, except in the remote northern regions where lightning is non-existent.

1.2 This Technical Note presents a simplified summary of lightning data from several technical sources in a manner that permits a quantized approach to the problem. It then goes on to discuss protection principles, and concludes with definite system recommendations. This note is not intended as a rigorous treatise on lightning because such is not helpful for the intended task of deducing engineering solutions. Also, where source data is conflicting, judgmental decisions have been made without discussion by the author. 'Electrical protection Guide to Land-Based Facilities' by David Bodle was particularly helpful in providing useful technical data (Reference 1).

LIGHTNING CHARACTERISTICS AND INCIDENCE

2 The concern here is with the type of lightning strike caused by the discharge of energy from an electrically charged cloud to ground (not cloud to cloud). Most electrical storms of this type are localized, short in extent, and caused by localized air heating and convection. A less common but more troublesome type of storm is the frontal type (extending up to several hundred miles) of the meeting of warm-moist and cold air masses.

2.1 The incidence of electrical storms without regard to their type is shown for the USA and Canada is figures 1 and 2 respectively. These maps are available from weather bureaus in USA and Canada. It may be seen that the USA experiences more electrical storms than Canada with a peak incidence in central Florida extending over the southern states. The average number of strikes per square mile resulting from frontal storms may be deduced from these incidence maps by multiplying the contour number by factor 0.37 (Reference 2). For example, central Florida will have up to 37 strikes per square mile, per annum.

2.1.1 Considering now that an antenna of h (height) feet essentially shields an area of approximately $9\pi h^2$ square feet, a radius of three times the height then the actual strike incidence at a particular antenna site, where frontal storms are predominant, will be the contour number multiplied by a factor of $0.375\ h^2 \times 10^{-6}$. Where convection storms are predominant the factor reduces to approximately 75 percent of the frontal storm value. Two examples follow:

Frontal storms:	Contour factor - 100, Antenna - 500 feet: Antenna strikes per annum = $100 \times 0.375 \times 500^2 \times 10^{-6}$	= 9.4 strikes
Convection storms:	Contour factor - 10, Antenna - 500 feet: Antenna strikes per annum = $10 \times 0.375 \times 500^2 \times 10^{-6} \times 0.75$	= 0.7 strikes

If the antenna is not situated on a flat area but on a local small hill, then the antenna height could be increased by the hill height for this calculation.

2.2 Having established the incidence of strikes at a particular location, the next important considerations are the actual electrical parameters of the strike. Some simplifying assumptions are necessary.

2.2.1 The main stroke of a lightning strike is characterized by a rapid rise and near-exponential decay of current essentially from a high impedance source comprised of a long length of ionized air. Presumably the inductance of the air path determines the rate of rise of the current and the resistance determines the current peak value and decay rate.

2.2.2 Hence a median main strike pulse may be considered as a uni-directional near-exponential pulse of 20,000 amperes peak amplitude lasting 40 microseconds to half amplitude. There is a five percent probability that the pulse amplitude is four times greater than the median value.

2.2.3 The rise time of a typical strike pulse is of the order of five microseconds to peak amplitude.

PROTECTION PRINCIPLES

3 A lightning strike is a discharge from a charged cloud into the semi-infinite reservoir, which is referred to as 'ground'. Unfortunately, at the surface of the earth an ideal terminal connecting to the ideal ground is rarely available -practical terminals will connect to it via a finite impedance ranging from a few ohms to several hundred ohms.

3.1 If now, for example, lightning strikes a radio tower with local grounding either directly (grounded tower) or via a spark gap (insulated tower) then the large current pulse flowing through the local ground impedance would develop a very high potential with respect to ideal ground. For example: with a median current pulse of 20,000 amperes and an impedance to ideal ground of say 50 ohms, this potential would be one million peak volts. If now the antenna local ground is connected via surface cabling to remote grounds, then a substantial part of the discharge current could flow through this connection into the remote grounds. The real connection to ideal ground becomes a parallel combination of all possible paths to the ground. This is the actual situation, because the local antenna ground is one terminal of the antenna for transmission purposes and requires a drive connection - usually the outer shield of the coaxial cable.

3.2 From the above discussion, it may be inferred that the first and most important principle is to provide the best possible (lowest impedance) local ground at the antenna. It cannot be assumed that the antenna ground mat necessarily has a low impedance to ideal ground. In poor soil conductivity or in frozen soil it may function as a good counterpoise type ground mat, yet have high resistance to ground. The ground mat must be supplemented by a ring of driven ground rods as described in 4.10 below.

3.3 Having provided the best practical antenna ground, it will still have a finite impedance to ideal ground and some component of the strike current will flow along the coaxial cable outer shield to remote grounds. This current will induce a high voltage between the inner and outer of the coaxial cable at the transmitter end of the cable (which must be protected against), but the first concern is the actual path that the current takes in finding remote grounds. The second principle, therefore, is that this current must not flow through the transmitter itself. To invoke this principle requires a clear understanding of all the possible remote ground paths (i.e.; local ground, incoming ac line supply, audio and remote monitoring and control cables and so on) and a careful arrangement of the ground connections within the transmitter building. Figure 8 illustrates this principal for a typical transmitter site. As shown, the current resulting from a direct strike on the antenna will flow to the ground via both the antenna's lightning ground system and via remote grounds composed of the ac line and control/ monitor cabling connecting to the transmitter site.

3.4 *The desired path for these currents to remote ground is achieved by ensuring that all ground paths which* interconnect the antenna and the transmitter building, including ground straps and the shield of any ac line cables, etc., are connected directly and solidly to a single point within the transmitter building referred to as the station reference ground point. This point is in turn connected via short heavy conductors to the ground terminals of surge arrestors connected directly across all incoming cables such as the ac line supply and control/monitor cables. In addition, all connections to the transmitter are threaded through the centre of ferrite cylinders, which act as chokes, *discouraging the flow of lightning currents through the transmitter cabinet.*

RECOMMENDED INSTALLATION CONFIGURATION

4 The precautionary measures illustrated in figure 8 are keyed to the text below which provides more specific details of the recommended installation configuration.

4.1 **SURGE PROTECTORS ON INCOMING CABLES** (see figure 1 on figure 8):
Each conductor of all cables which interconnect the transmitter building to remote locations must be bypassed by a suitable surge protector to the station reference ground point as shown in figure 8. More specific details are shown in figure 4. The most important surge protectors, namely those connecting to the ac line supply are covered in more detail in paragraph 6. These surge protectors serve the dual function of bypassing surges which originate at sources which are remote from the transmitter site (such as lightning strikes on ac power distribution wires) but, more importantly to provide a safe path for the currents resulting from direct lightning strikes to the station's antenna. As described in paragraph 2.3, current surges exceeding 20,000 amperes can be anticipated and the surge protection devices must be rated accordingly. The total surge current will be shared between the antenna's lightning ground rods and the various cables that connect the transmitter building to remote grounds depending upon the relative impedance of each path. Generally, the ac line supply will present quite a low impedance due to its heavy wire size and its wide distribution to other ground connections. It is therefore recommended that ac line surge arrestors should be capable of carrying multiple 20,000 amp surges without deterioration. The suppressor must also maintain the surge voltage developed across it within safe limits and return to a non-conducting state without removal of the normal working voltage following the surge condition. Lower surge current ratings may be suitable for other remote cabling due to the relatively smaller cable sizes and corresponding higher impedance.

4.1.1 Varistor type elements are considered the most satisfactory for all of the above purposes due to their ruggedness and self-restoring characteristics. Two back-to-back zener diodes can also be used to form a passive shunt clipping element in the same manner as a varistor. They exhibit lower ratios of clipping to working voltage but are not presently available with comparable surge current ratings.

4.2 **STATION REFERENCE GROUND** (see 2 on figure 8): It is of utmost importance that the station reference ground point be configured as shown in figure 8 with all of the ground connections coming together at a single point. This point must be located in close proximity to the surge protectors for the ac line remote cabling and be connected to them by short heavy straps.

4.2.1 It would not, for example, be sufficient to connect interconnecting grounds from the antenna system to a safety ground bus inside the transmitter building which is distant from the reference ground point. Likewise all equipment, safety ground connections should be connected in a radial manner as shown.

4.2.2 The station reference ground should be connected via a heavy strap to at least two ground rods separated by two or three times their length and driven well below the frost line into the available water table.

4.3 **FERRITE CHOKES** (see 3 on figure 8): Ferrite cylinders (toroids) threaded over the cables that connect to the transmitter provide the useful function of increasing the impedance of undesired current paths through the transmitter cabinet. It is important to ensure that all conductors of the ac line supply and the inner and shield of all coaxial cables pass through the respective cylinders so that they are transparent to the desired signal (forward and reverse currents cancel) but, provide an impedance to undesired unbalanced currents.

4.3.1 With very large transmitters where coaxial cable diameters exceed two inches, it is difficult to obtain ferrite toroids large enough to fit over the feeder cable. Under these conditions it is permissible to omit the ferrite cylinders from the feeder cable while correspondingly increasing the number of toroids used on the remaining transmitter connections and ensuring that the ground wire of the ac line cable also passes through the toroid.

4.4 SURGE PROTECTORS AT TRANSMITTER'S OUTPUT (see 4 on figure 8): With a direct lightning strike on the antenna some lightning energy will inevitably penetrate the external protective devices and enter the transmitter via the coaxial feeder cable. This can result, for example, from lightning current flowing in the shield of the feeder cable, which in turn induces some of its energy into the centre conductor.

4.4.1 To provide additional line of defence, an air ball gap and a gas tube protector are connected in parallel across the transmitters output circuit. The ball gap provides a rugged high current shunt element. The gas tube has a much more closely defined breakdown voltage but is less rugged and has a life limitation of a finite number of surge discharges. This limitation is expressed as a coulomb (amp-sec) capacity. The gas tube device may therefore require periodic replacement depending upon the strike frequency and intensity.

4.5 GROUND STRAP BETWEEN ANTENNA AND TRANSMITTER BUILDING (see 5 on figure 8): Previous technical notes on lightning issued by Nautel have recommended that straps joining the antenna's ground plane to the transmitter building be avoided. The foregoing discussion of providing a lightning current path from the antenna to remote grounds which is as isolated as possible from the transmitter suggests, however, that a ground strap can be used to advantage for this purpose. Unlike lightning currents flowing in the screen of the coaxial feeder cable, currents in this ground strap will not induce transients into the inner conductor of the coaxial feeder, connecting them to the transmitters final amplifier circuits. If the ground strap is used, it must be directly connected to the station reference ground point as shown in figure 8. An additional ferrite choke may then be used to advantage on the coaxial feeder cable between the transmitter building and the tuning house.

4.6 *ANTENNA TUNING UNIT SPARK GAP* (see 6 on figure 8): It is recommended that an air spark gap be installed within the antenna tuning unit in shunt with the rf signal path. The size and ruggedness of this device may be considerably smaller than the spark ball gap at the base of the antenna. Since the breakdown voltage of small spark gaps is dependent upon both the gap spacing and the shape of the electrodes it is not possible to provide precise gap setting information. The gap must, however, be set so that breakdown never occurs due to the normal rf working voltage. Where the tuning arrangements do not provide a dc path from the antenna feed wire to ground, a static discharge choke must be connected in parallel with the spark gap.

4.7 ANTENNA FEED WIRE (see 7 on figure 8): A common inexpensive method of reducing lightning current in the antenna fed wire is to form it into one or more loops an inch or two in diameter to form a low but finite series inductance.

4.8 BALL GAP ACROSS BASE *INSULATOR* (see 8 on figure 8): This is the most important protective device for base insulated towers. It consists of a pair of tungsten spark-balls with an insulating air gap between them. The device is very rugged, easily inspected or repaired and is widely used at the base of antenna towers where it serves as a crude, but effective first-line lightning protector. Mounting arrangements should be rigid enough to maintain the gap separation during severe weather conditions. The balls should be aligned on the horizontal plane, rather than vertical to prevent water drops from reducing at the effective gap separation.

4.8.1 Breakdown voltage of the gap will vary with air pressure (and hence altitude) and its breakdown voltage is greatly increased for rapidly rising potentials. At sea level and for large spheres, the breakdown potential at 1mHZ is approximately 9.4kV peak per 1/8 inch gap. A rough rule of thumb for setting the gap is to allow 0.020 inch per peak kV at the antenna base. This should be increased at high altitudes. The peak antenna voltage may be calculated from:

$$V_{peak} = 2.83 \times Za \times Ia$$

Where Za = antenna impedance, ohms
Ia = antenna current, amps rms

4.9 ANTENNA GUY WIRES (see 9 on figure 8): The lower end of each guy wire should be electrically connected to one of the ground plane radials by a copper conductor. These connections will allow proper functioning of the guy wire isolators. It is recommended that the guy wire insulators be periodically inspected for evidence of electrical/mechanical breakdown.

4.10 ANTENNA LIGHTNING GROUND SYSTEM (see 10 on figure 8): As discussed in paragraph 3, the antenna's lightning ground system must provide the lowest possible impedance to ideal ground. A ring of four driven ground rods long enough to penetrate well below the deepest frost level and into the available water table will usually provide a satisfactory connection. (Your local electrical power utility company may provide good advice on this subject). The rods should be separated by approximately two or three times their length and should connect separately via heavy straps to the antenna base ground terminal.

4.11 GROUND PLANE RADIALS (see 11 on figure 8): The system of copper radials commonly used as the antenna's ground plane must be connected together at a ring or common point adjacent to the base of the tower. A heavy copper strap must connect this common point to the lower end of the base insulator with a good electrical connection capable of carrying the total rf antenna current. All wire interconnections should be welded or silver soldered to ensure good electrical continuity in a corrosive environment.

TRANSMITTER BUILDING LAYOUT

5 The geometry of the interconnections in and around the transmitter 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 line supply, which does not include the interior of the building.

5.1 IDEAL BUILDING LAYOUT: Figure 5 illustrates the ideal building geometry, in which the coaxial feeder cable and the ac line service enter the building in close proximity to one another. That station reference ground is established as a single point at this same location. The shield of the coaxial feeder is connected directly to the station reference ground together with the common terminal of the surge protector device. The line terminals of the surge protector connect, via short low inductance cables, to the lines of the ac power.

When using a phased directional antenna with the phasing equipment installed within the transmitter building, all coaxial feeders should enter at this same point and be grounded to the station reference ground. Where a building safety ground ring is installed, it should be connected directly to the station reference ground point. With this arrangement, most of the lightning current will tend to bypass the building interior due to the relatively low impedance of the desired path through the surge protector compared to that of the long loop in and out of the building which passes through the transmitter. At power levels up to 10 kilowatts, ferrite toroids may be threaded over the ac power and the coaxial feeder cables inside the building which act as rf chokes to the undesired lightning currents, but are transparent to the normal operating currents. This technique may not be possible for very large transmitters as the maximum internal diameter of commonly available, suitable 'ferrite toroids' is limited to about three inches.

5.2 POOR BUILDING LAYOUT: Figure 6 illustrates a very poor transmitter building layout which contains all the elements of the ideal arrangement shown in figure 5, but configured so poorly that little or no benefit will be obtained. This figure has been included ONLY to emphasize the importance of using the correct configuration.

The following fundamental errors are illustrated in figure 6:

(a) The ac power cable is fed from the left hand side of the building while the coaxial feed

(b) No station reference ground point has been established and ground points are picked up from the safety ground ring at various locations.

(c) Ferrite toroids have been threaded independently over each of the lines of the ac power source causing them to be completely saturated by the normal operating currents in these lines.

(d) The shield of the coaxial feeder cable is connected directly to the transmitter, hence lightning currents following in it will pass directly through the transmitter.

It is worth noting that even if the coaxial shield were connected to the building safety ground ring at the right side of the diagram, most of the lightning current would still tend to flow in the direct path thru the transmitter due to its relatively low impedance compared to the alternative longer path thru the safety ground ring and the surge protector.

(e) The safety ground connection of the transmitter being connected at the right hand side of the diagram provides another undesired path for lightning currents flowing in other ground interconnection between the antenna and the transmitter building.

5.3 CORRECTING A POOR BUILDING LAYOUT: On existing installations, it is often impractical to re-configure the layout to conform exactly with the ideal arrangement. The following factors should however be carefully considered when attempting to improve the layout.

(a) The ac line supply, the coaxial cable and all other cables including ground connections which connect to the equipment to be protected, must be brought into close proximity with each other at the station reference ground point before feeding to this equipment.

(b) The term 'equipment to be protected' used in (a) above will ideally include the entire transmitter building. (With this arrangement, both personnel and all equipment within the building are protected). The principle may in some cases be applied only to an area in the building or to the radio transmitter alone due to logistical difficulties.

(c) All incoming ground conductors should be connected directly to the station reference ground point, which in turn should be connected radially to all equipment grounds in the building.

(d) A set of varistors or similar devices capable of carrying the lighting current should be connected via short cables between the station reference ground point and the conductors of the ac line supply.

Figure 7 illustrates a method of corrections for a non-ideal building layout, where the ac line service is connected at a location which is widely separated from the entry point of the coaxial feeder and the antenna ground strap. It should be noted that the coaxial cable should not contact any grounds within the building prior to being connected via a short strap to the station reference ground. It should also be well out of reach of personnel working in the building to ensure their safety during lightning storms.

AC LINE SURGE PROTECTORS

6 The ac line supply to the transmitter building usually represents the lowest impedance to remote grounds and will therefore carry most of the lightning current flowing away from the transmitter site. The surge protectors that connect between the station reference ground and the ac line cables must therefore be rated to carry most of the anticipated lightning current. It is also important that the potential developed across the protectors by the lightning current flowing through them is balanced with respect to all of the lines, so that no net lightning potential appears between any ac supply lines to the transmitter. This is not possible to achieve, however, with single-phase supplies or with some three-phase supplies that are not balanced with respect to ground potential.

The voltage rating of the surge protectors should be chosen such that the prevailing off load steady state voltage is safely below the minimum turn-on voltage.

IMPLEMENTING PRACTICAL SOLUTIONS

7 'An ounce of prevention is worth a pound of cure' is a well-known adage which is high applicable to lightning protection. It is strongly recommended that comprehensive preventive measures be installed on all transmitter sites. Antenna arrestors and an effective antenna ground are considered mandatory at any site if for no other reason than the safety of associated personnel. The configuration of individual transmitter sites will seldom be identical to that shown on figure 5. It is hoped, however, that this model will give the reader a better understanding of the underlying principles and the ability to design a satisfactory protective scheme for a particular site. It is worth noting that amount of potentially destructive lightning energy and hence the cost of protecting a transmitter site, is not related to the size of the transmitter. The amount of money worth spending at a particular site is, however, related to the cost of the equipment being protected and to its statistical probability of experiencing lightning strikes as described in paragraph 2.

7.1 Nautel can supply a range of protective devices including toroidal ferrite cores and shunt surge protectors from a variety of component manufacturers, which may be utilized to provide necessary protection for its radio transmitter systems within particular environments.

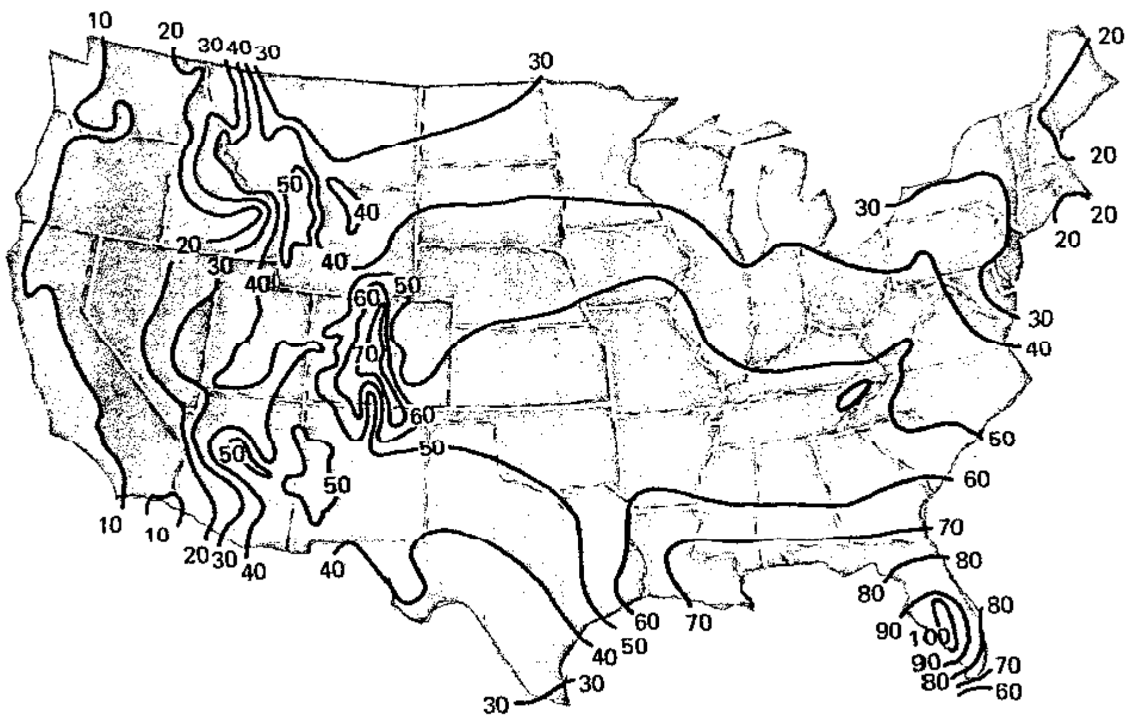

Figure 1 Mean Annual Number Of Days With Thunderstorms In The United States

Figure 2 Annual Average Number Of Days With Thunderstorms In Canada

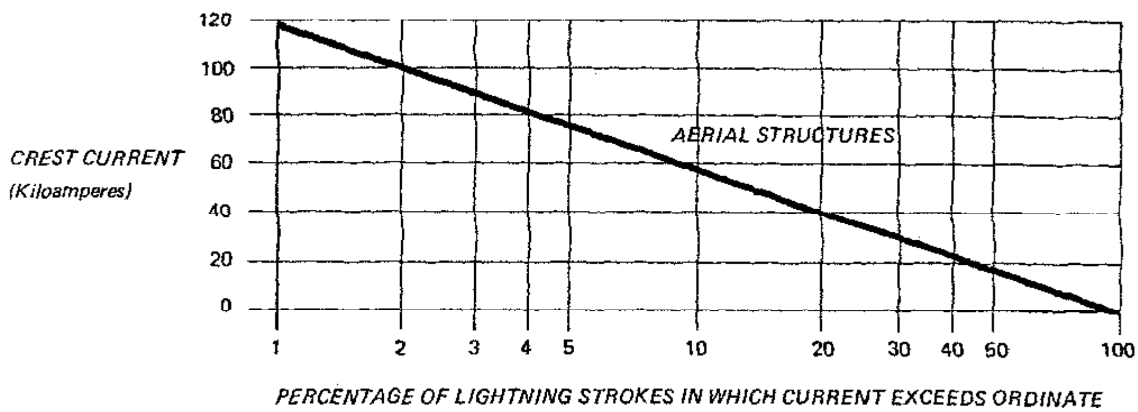

Figure 3 Magnitude Distribution Of Currents In Lightning Strokes To Structures

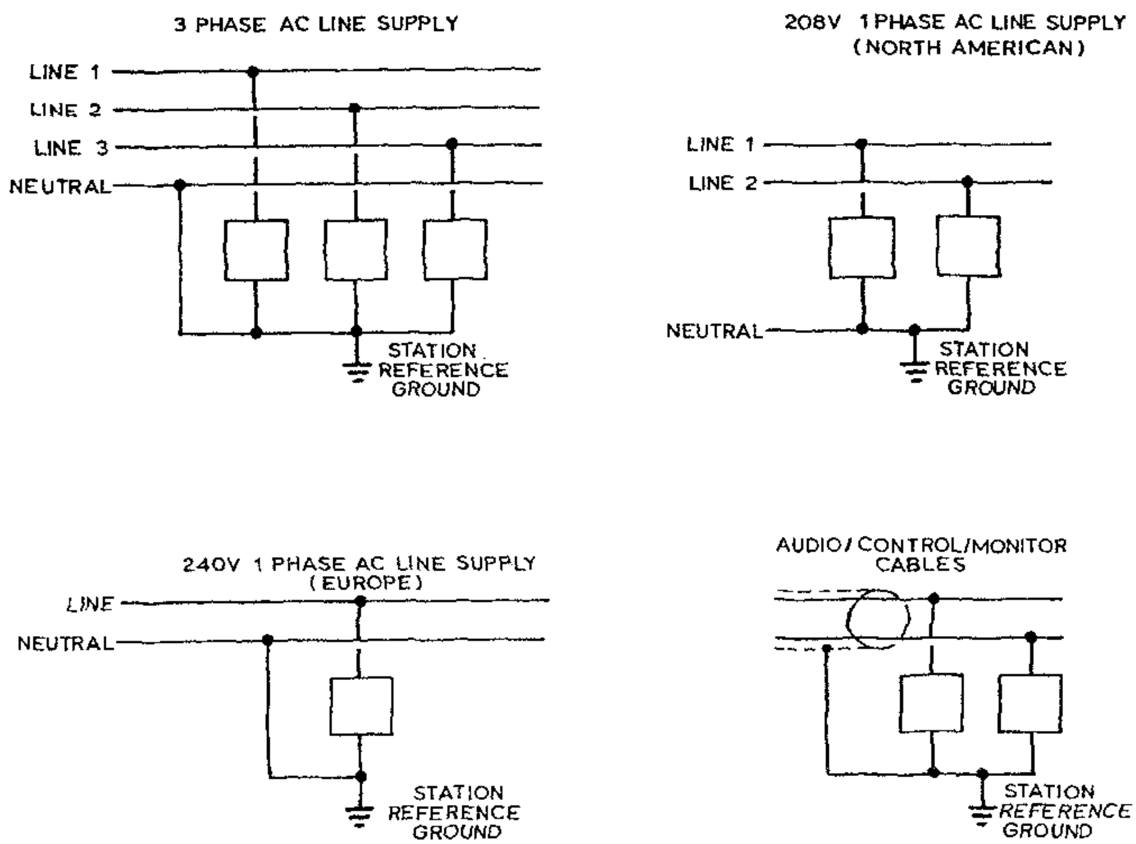

Figure 4 Surge Protector Connection On Power, Audio, Control And Monitor Wires

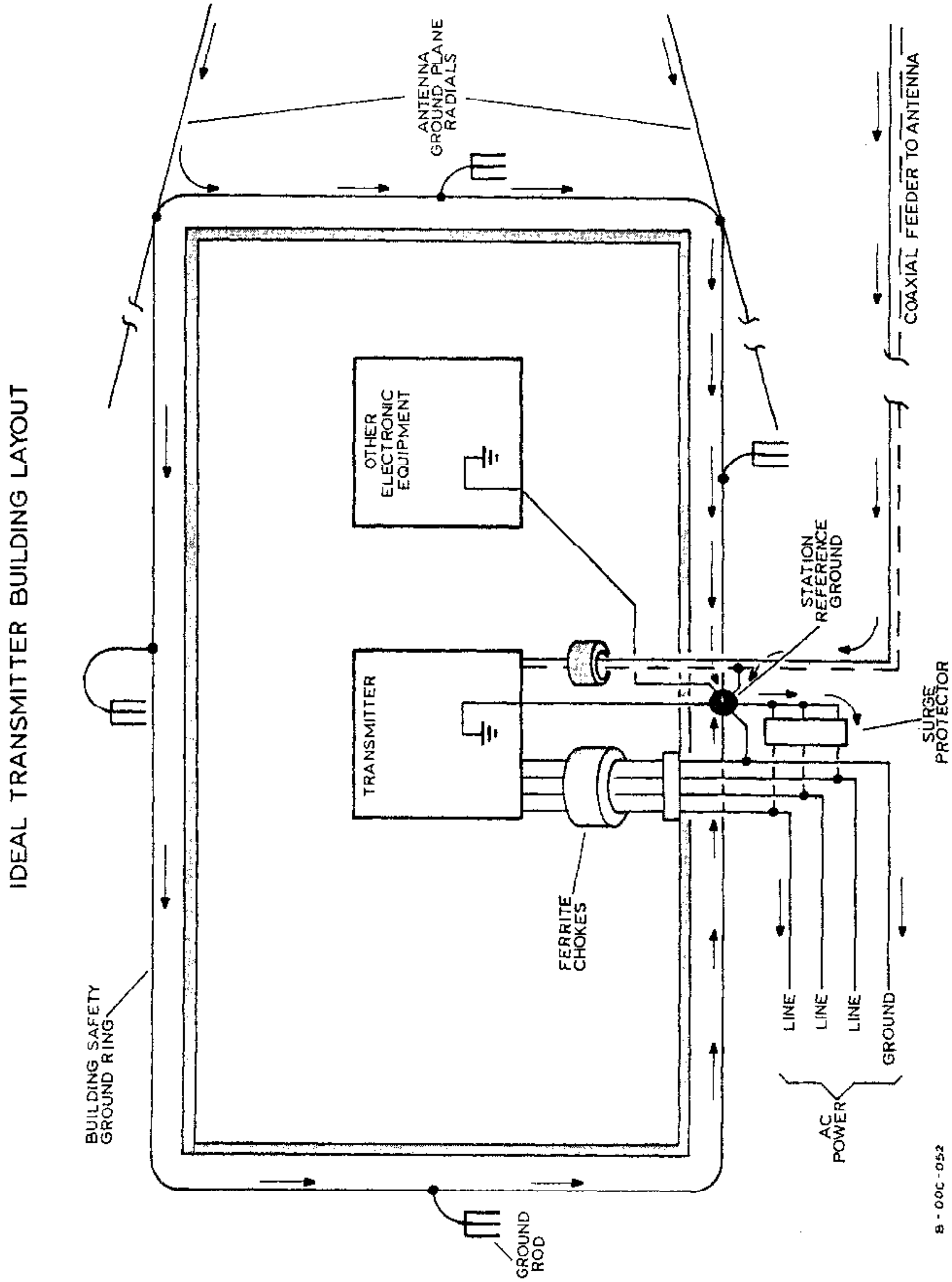

Figure 5 Ideal Transmitter Building Layout

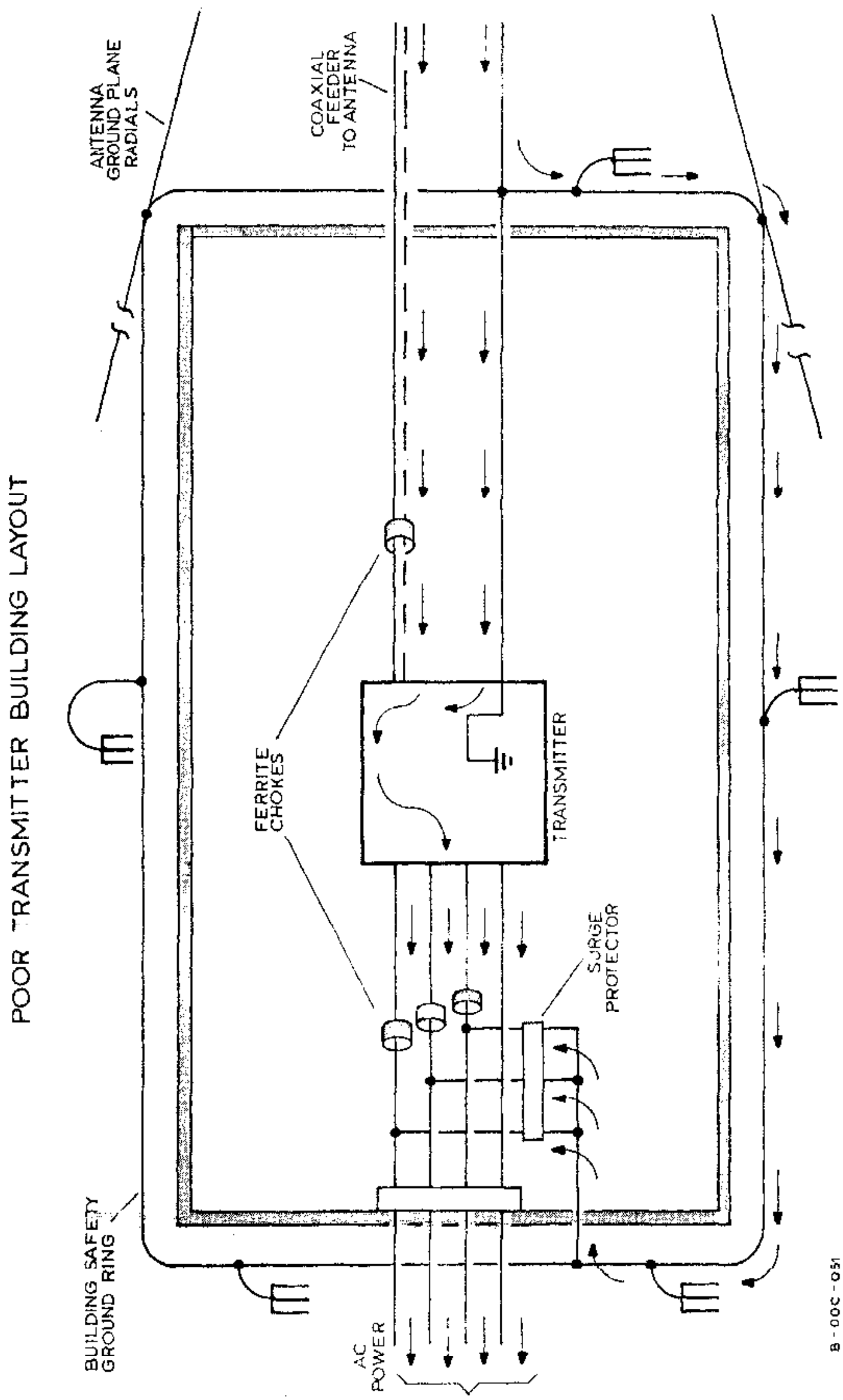

Figure 6 Poor Transmitter Building Layout

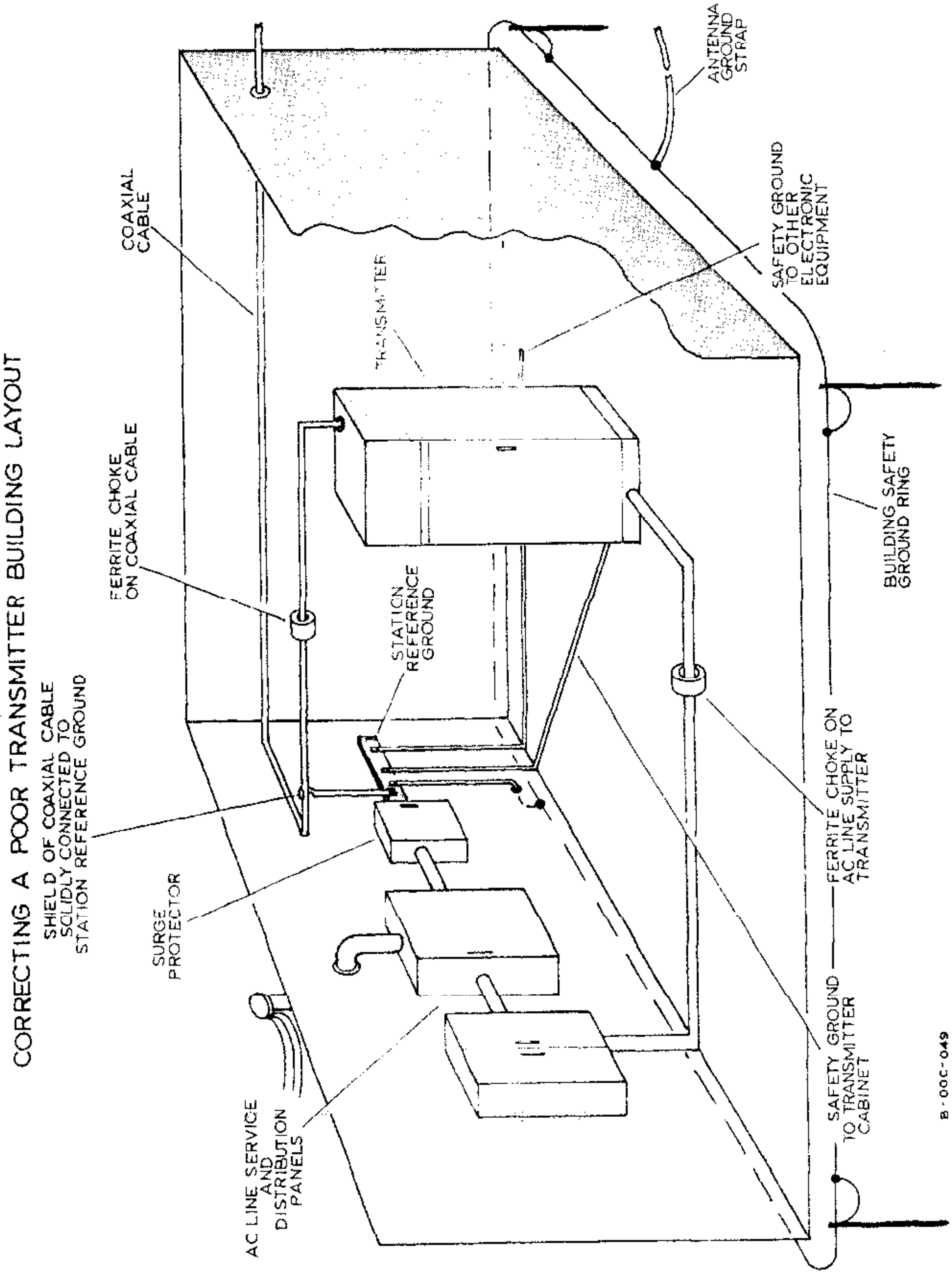

Figure 7 Correcting A Poor Transmitter Building Layout

REFERENCES:

(1) Electrical Protection Guide for Land Based Radio Facilities by D. Bodle, Joslyn Electronic Systems, 1971.

(2) Lightning Observations in Buried Cables, H.M Trublood and Ed Sunde, Bell System Technical Journal, XVIII, April 1949.

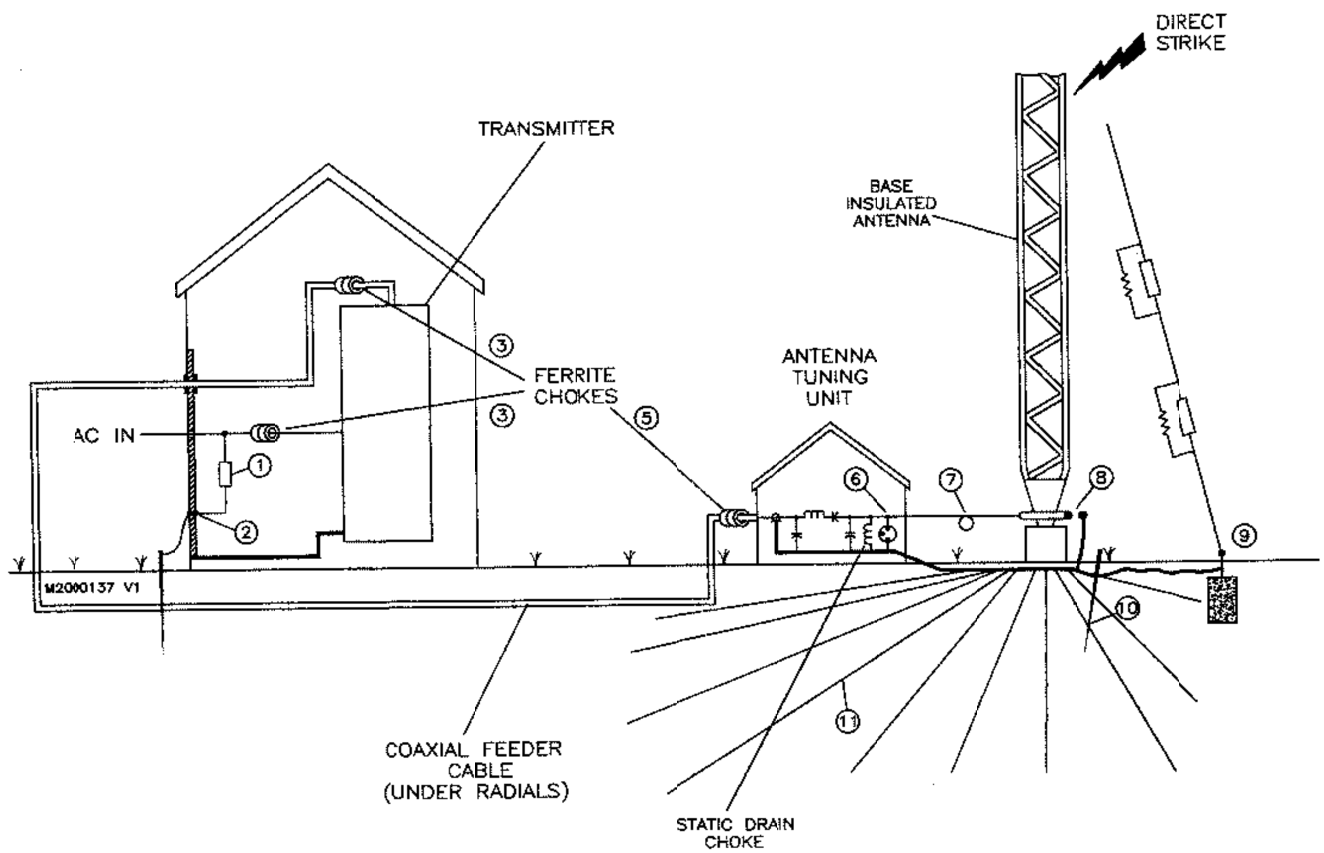

Figure 8 Recommended Installation Configuration