

Recommendations for Transmitter Site Preparation

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Nautel Limited
10089 Peggy's Cove Road,
Hackett's Cove, NS, Canada B3Z 3J4
T.877 6 nautel (628835) or +1.902.823.2233
F.+1.902.823.3183 info@nautel.com

U.S. customers please contact:
Nautel Inc.
201 Target Industrial Circle, Bangor ME 04401
T.877 6 nautel (628835) or +1.207.947.8200
F.+1.207.947.3693 info@nautel.com

e-mail: support@nautel.com
www.nautel.com

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THE INFORMATION PRESENTED IN THIS DOCUMENT IS BELIEVED TO BE ACCURATE AND RELIABLE. IT IS INTENDED TO AUGMENT COMPETENT SITE ENGINEERING. IF THERE IS A CONFLICT BETWEEN THE RECOMMENDATIONS OF THIS DOCUMENT AND LOCAL ELECTRICAL CODES, THE REQUIREMENTS OF THE LOCAL ELECTRICAL CODE SHALL HAVE PRECEDENCE.

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Release Control Record

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1.0	01 July 1998	Original Issue
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3.0	22 September 2004	Reformatted; changes to site checklist
3.1	09 May 2008	Figure 8: added note re. grounding of coaxial feeder cable

Recommendations for Site Preparation

1 INTRODUCTION

A good transmitter site can ensure many years of reliable performance, while a bad site will result in unpredictable or unsatisfactory performance. This paper identifies the characteristics of a good site and provides advice on how to achieve these.

1.1 Potential Threats:

There are many threats to electronic payloads at a transmitter site. Some of these are common to any modern electronics system, while others are unique to the mission performed by a transmitter. The following must be considered:

* lightning
* man made power line transients
* high electromagnetic (EM) fields near an antenna
* arcing in the impedance matching/ phasing networks, RF feed cables (birds etc)
* cooling problems
* routine maintenance activities
* repair activities
* entrance of foreign matter (snakes, rodents, etc)

1.2 Advantages:

It is now accepted that there are many advantages to a fully solid state transmitter. Some of these are:

* high efficiency (85% typical)
* no tube to wear out
* lower DC voltages
* redundancy
* modularity allowing on air servicing
* improved audio performance
* increased modulation capability

The advantages are only realized when due attention is given to the potential threats. It may not be possible to gain the advantages available from solid state transmitters at existing tube-transmitter sites by simply replacing the transmitter. A complete audit of the site is needed, with possible upgrading in areas highlighted in the rest of this paper.

While this information is intended to be valuable, it is not a substitute for a competent site contractor.

2 LIGHTNING THREATS

A transmitter site and its electronic payload must be considered as a system for the purpose of lightning protection. A solid state transmitter's internal protection circuits/ devices are not able to protect the transmitter from damage as the result of a direct lightning hit to its antenna, by themselves. They must be supplemented by additional protection devices, at the antenna and on the wiring entering the transmitter cabinet, which will divert energy away from the transmitter.

Refer to Appendix 'A' for modern statistics on the nature of a lightning stroke and to Appendix 'G' (***Nautel's Lightning Protection for Radio Transmitter Stations*** booklet) for additional data.

2.1 Air Spark Gap:

The most important lightning protection device is a properly adjusted air spark gap, that is located at the base of the antenna and is connected to the lowest possible ground impedance. This air spark gap must be considered as the first line of defence against lightning. Its principle function is to shunt the majority of lightning currents to a low impedance ground at the base of the antenna. When properly adjusted, it will minimize the transients flowing towards the transmitter through the coaxial RF feeder.

The air spark gap at the antenna should be a ball gap type in preference to some of the other small radius devices that are in use. A spark ball type air gap is known to offer faster breakdown at repeatable voltages. Spark balls that are between 25.4 mm (1 inch) to 50 mm (2.0 inch) in diameter are best for lightning protection. They create an almost uniform field situation, which improves the predictability of the gap setting needed. It is recommended the balls be manufactured from very hard, low impedance materials such as carbon or tungsten. This will minimize damage to the balls when they perform their function. Spark balls should be aligned in the horizontal plane, to ensure rain, etc will not bridge the gap. Clouds of flying insects have been known to initiate premature breakdown. The area around the tower base should be kept free of high grass and other vegetation. It is recommended the spark balls be located in a weather/insect/rodent proof enclosure.

Appendix 'B' provides formulae for determining the air gap setting. Note, the breakdown strength of air at 1.0 MHz is about 80% of its low frequency value, which is 30 kV/cm. Appendix 'C' identifies a source for ball gaps.

2.2 Ground Rods:

It cannot be assumed the antenna ground mat provides a low impedance to the ideal ground. In poor soil conductivity or in frozen soil, it may function as a good counterpoise, yet have a high resistance to ground. The ground mat must be supplemented by a ring of at least four, driven, ground rods which should be as long as possible (typically 3 to 4.5 metres [10 to 15 feet]). They must penetrate well below the deepest frost level. Separation of the rods should be two to three times their length. They should connect separately via heavy strap to the antenna base's ground terminal together with the mat. The objective should be to obtain the lowest possible inductance as well as the lowest possible resistance. Refer to Figure D-4 of Appendix 'D' for wire inductance information.

2.2.1 Ground Rod Depth:

The total depth each ground rod must be driven into the soil depends on soil conductivity. Soil resistivities vary greatly depending on the content, quality and the distribution of both the water and natural salts in the soil. It is beneficial to reach the water table, but it is not necessary in all cases. In higher latitudes, rods should be long enough to penetrate below the maximum frost depth. In most cases a total depth of 12 metres (40 feet) or less is necessary, with the average being 4.6 metres (15 feet). Depth also depends on the number of rods and the distance between them. Table 2-1 provides typical resistive measurements for different soils. The resistivity of a given soil will vary with moisture.

Table 2-1 Soil Resistivities

PHYSICAL COMPOSITION OF SOIL	RESISTIVITY IN OHMS/METRE
Sea Water	1 to 2
Marsh	2 to 3
Clay	3 to 160
Clay mixed with Sand and Gravel	10 to 1,350
Chalk	60 to 400
Shale	100 to 500
Sand	90 to 800
Sand and Gravel	300 to 5,000
Rock (normal crystalline)	500 to 10,000

2.3 Static Drain Choke

A static drain choke should be installed at the base of the antenna, preferably across the air spark gap. Its purpose is to provide a DC path to ground and bleed off any static charge on the antenna. Sometimes the antenna tuning unit will have an inductor that performs this function. Depending on its proximity to the antenna, this inductor may or may not be adequate. Transmitters often have an internal drain choke connected to their output termination point. The purpose of this choke is to bleed any static charge on the RF feed to ground, before it reaches the RF output filter. If there is a series capacitors in the RF feed between the transmitter and the antenna, any internal choke will not be able to assist in bleeding off static charges on the antenna.

2.4 Static Drain Resistors:

Static drain resistors should be connected across guy wire insulators. Their purpose is similar to that of the static choke. They should bleed off any static charge, on the antenna side of the insulators, caused by blowing snow, dust or other environmental conditions, before the static potential is sufficient to cause arcing across the insulators.

2.5 Series Capacitor:

It is recommended a series, DC blocking capacitor be installed in the RF feed between the transmitter and the antenna. It will be very helpful in reducing current flow to the transmitter's RF power stage during the "continuing currents phase" of a lightning strike. This phase, which occurs immediately after the very fast rise of the lightning impulse, usually has a duration of 40 to 500 milliseconds and transfers the bulk of the lightning charge (between 50 and 500 amperes). A representative lightning stroke delivers about 25 coulombs, with 75% of this delivered in the 'continuing currents phase'. A series, DC blocking capacitor will present a high impedance to the low frequency component of lightning strikes and significantly restrict the flow of unwanted transients, from the antenna to the transmitter, in the RF feed coaxial cable.

2.6 Single Point Ground:

It is recommended a single connection point to the station reference ground be established, preferably where the AC power wiring and the RF feed's coaxial cable enter the transmitter building. The purpose of this ground is to prevent ground loops and to ensure unwanted currents do not flow in the transmitter cabinet. The shield of the RF feed cable, the ACower ground, the ground return for the AC power suppression system and the transmitter's reference ground point should all be individually connected to this point; by insulated, low inductance, low impedance, ground straps. This concept is depicted in the simplified schematic and ideal transmitter building layout drawings provided in Appendix 'D'.

2.7 Diversion of Transients on RF Feed Coaxial Cable:

Even with an excellent low resistance ground at the base of the antenna, some current will flow through the shield of the antenna's coaxial RF feed cable, towards the transmitter. It is vital that this current be diverted to ground, away from the transmitter, at the point where the coaxial cable enters the transmitter building. The coaxial shield must be connected directly to the common ground point by a low inductance, low impedance, ground strap. This is the reason we recommend the entry point for the RF feed's coaxial cable be in close proximity to the station reference ground's common point.



2.8 Diversion/Suppression of Transients on AC Power Wiring:

Another point of entry for damaging transients is the wiring from the AC power source. A direct lightning hit to the wiring is possible. Common mode transients can also be induced into underground wiring. The defence here is a line transient suppressor system consisting of shunt varistor elements and often, series impedances in the form of air cored line inductors (around 15 uH). The building entry point for the AC power wiring and the location of the transient suppressor system must be in close proximity to the station reference ground's common point. The AC ground and the ground return for the transient suppressor system should be connected directly to the common ground point by a low inductance, low impedance, ground strap. This will ensure transients are shunted to the station reference ground by the line transient suppressor system, and diverted away from the transmitter where the wiring enters the building.

2.9 Shielded Isolation Transformer:

An additional protection scheme, which has recently been shown to be effective, is the use of a shielded, isolation transformer between the AC power source and the transmitter. They are normally 1:1 power transformers which employ a shielding technique that enables them to block common mode transients over a broad range of frequencies without impeding the normal AC signal. To be effective the shield must be connected to the station reference ground at the common point by a low inductance, low impedance connection. This is normally achieved by using a wide copper strap that is as short as possible. Failure to provide a low impedance, non-inductive ground will allow the shield potential to rise and couple transients to the secondary. Ordinary transformers have a high primary to secondary capacitance (2000 pF) and offer much less protection than once thought. They can easily couple the fast edge of a common mode transient from their primaries to their secondaries.

3 ELECTROMAGNETIC SUSCEPTIBILITY

The electrical field strength (E) at the base of an antenna can be in excess of 50 V/m. To put this in perspective, it is useful to examine field strengths employed when performing susceptibility testing on high quality electronic equipments. There are no legislated requirements. Typical testing for commercial equipment is performed at 2 V/m, while equipment intended for the most arduous circumstances must pass a test at 10 V/m. From this we can see that any electronic system attempting to function in this environment is in jeopardy. Consequences range from degradation in performance to actual damage/destruction. Appendix 'F' contains additional electromagnetic susceptibility information. A number of practices are witnessed at a good site, they include:

3.1 Shielded Building

A shielded building provides global protection for all of the equipment at the site, and is highly recommended for trouble free operation. This is just a Faraday Cage but on a larger scale. Figure F-3 of Appendix 'F' depicts a method of adding a shield to an existing site. It involves extending conductors, which are connected to the building's safety ground ring, over the building and connecting the ground ring to the antenna's ground radials.

3.2 Routing of RF Feed Coaxial Cable:

To prevent the shield of the RF feed's coaxial cable and the transmitter itself, from becoming part of the antenna counterpoise, it is good practice to bury the RF feed coaxial cable below the ground mat formed by the antenna radials.

3.3 Ferrites for Rejection of Common Mode Signals:

It is recommended that wires or groups of wires (AC power, audio, control, monitoring, etc) which enter the transmitter cabinet, be routed through ferrite toroids before they enter the cabinet. The inductance formed by these ferrites would be transparent to differential mode signals (intended currents), but would exhibit a high permeability and act as a choke for common mode signals, such as RF pick-up from the antenna.

3.4 EMI Filters:

RF on the AC power source for the transmitter may need to be eliminated by a filter. Large three phase filters are available. Their normal application is to minimize EMI leaving equipment they are installed in, but they are still useful for the situation described here.
It should be noted that many sites have multiple transmitters operating simultaneously, even into the same antenna. The effects of this contamination can vary, depending on how the RF energy is processed by the unintended receiver. It may be rectified by protection diodes and result in DC offsets in other circuits. If it is at the same frequency as the transmitter, (i.e., from the transmitter or co-located backup) it can result in instabilities. It is even possible components may be damaged.

3.5 AC Power Sources Not Recommended for Use:

Open delta, or 'V-V' connected three-phase AC power sources, which utilize two identical transformers, are not recommended for use with Nautel transmitters. These systems are susceptible to third harmonic distortion and line transients that are normally nullified in a standard wye-delta transformer connection. Imbalances resulting from these factors may cause non-sinusoidal peak voltages in excess of the supplied line voltage. When applied to the transmitter's three-phase load, this can translate into increased power supply noise or cause component (e.g., rectifier) failure.

To improve regulation and reduce the third harmonic content and transient susceptibility, it is recommended that an open delta AC power source be converted to a 4-wire wye (star) configuration with the three phases balanced to ground.

4 HIGH VOLTAGE BREAKDOWN CONCERNS

Solid state transmitters have fast acting VSWR protection circuits that are intended to shut down RF power stages before damage can occur. They are intended for occasional trips that are caused by abnormal conditions, such as lightning strikes. They will also react to high voltage breakdowns in the RF path caused by site shortcomings. Repeated arcing due to high voltage breakdowns will eventually damage a transmitter.

4.1 RF Transmission Systems

The RF transmission system, from the transmitter flange to the antenna, must be studied and tested before a transmitter is placed in operation. The testing must verify the entire system can withstand the expected peak voltages of normal operation, especially those occurring during modulation peaks, without breaking down. A site is often reused after a previous owner has left it. If a solid state transmitter is to be installed in one of these sites, especially if it will radiate a higher power, this testing is extremely important. See Appendix 'F' for calculation of expected peak voltage.

4.2 High Voltage Feed Throughs

Whenever a high voltage RF conductor must pass through a bulkhead, extreme care must be taken. Gas insulation flashovers can occur in poor installations. The selection and installation of the feed through is a job best left to experts. However, it is worth pointing out some of the challenges involved in identifying weaknesses that might exist.

4.2.1 Insulator Flash Over:

Surface flashover along an insulator occurs when there is an electrical breakdown in the gas (normally air) at its surface. The mechanism that triggers the flash over depends on the insulation surface conditions. Under dry gas and clean insulator conditions, the criteria for a gas breakdown flash over is usually one of the following conditions:

(a) The voltage field at the insulator surface or at an adjacent electrode reaches the critical breakdown level for the gas.

(b) The electrode/insulator interface is poor, usually resulting in a three material junction. The consequences are excessive high voltage stress on the air insulator, which can initiate a gas breakdown flash over (see paragraph 4.2.2).

(c) Particulate or moisture damage on the insulator surface creates regions of high voltage fields sufficient to initiate a gas breakdown flash over

4.2.2 Three Material Junctions:
A frequent cause of breakdown at an insulator surface is the junction of three materials; a metal conductor, a solid insulator and a gas insulator. The insulators effectively form a capacitive RF divider between the metal conductor and the grounded periphery. Since the dielectric constant of the solid is higher than the gas (air), the high voltage stress is concentrated on the air. It is, therefore, very important to minimize the junction's stress gradient and to avoid triple junctions wherever possible. Failure to provide correct stress control at high RF voltage conductor/insulator junctions can result in insulator breakdown or even ignition of solid insulating materials and a subsequent fire. Figure E-1 of Appendix 'E' illustrates a triple junction interface and a method of minimizing the stress at such interfaces.

4.2.3 Bowl Type Bushings:
Bowl type bushing insulators are commonly used to increase the surface tracking distance from the central conductor to the grounded periphery or wall. Figure E-2 of Appendix 'E' depicts a typical bowl type insulator. Note that it contains a field control ring to minimize the conductor/insulator junction's stress gradient.

4.2.4 Insulator Breakdown/Damage:
An insulator can be damaged during gas breakdown flashovers. When current flows across the surface of an insulator, especially when it is coated with a conductive contaminant that is slightly wetted, sufficient heat may be generated to form a track of carbon. When this occurs, the track will be a conductive path, and reduce the effectiveness of the insulator. For other circumstances, a carbon track may not be formed, but pitting/erosion of the insulator surface may occur. Periodic cleaning of insulator surfaces and the use of good stress control techniques at the conductor/insulator junction will significantly reduce possibility of tracking damage.

4.2.5 Other Causes:
Other causes of breakdowns can be; improperly adjusted spark balls or the changing of their air gaps by an external influence such as rain, insects, birds, grass, etc (see paragraph 2.1 for spark gap information), birds on open wire transmission lines, or an accumulation of pollution (soot) on insulator surfaces.

4.3 Small Radius Conductors
Something to be wary of, is the use of small radius conductors to carry high RF voltages/currents. If the radius is not adequate, the result can be local corona, which will be a precursor to breakdown.

5 COOLING
Nautel installation instructions detail the required air flow along with the cooling options that are available. These instructions clearly identify the inlet areas and outlet areas. The fact that air filters are needed is spelled out. The situation at the actual site will dictate the kind of filtering needed. Some areas may be plagued with fine sand while others have insect problems. Even with all this we have seen sites with 2 cm of flies on the transmitter floor after only 6 months and other sites with the air inlets and outlets reversed.

5.1 Air Filters:
Air filters require cleaning or replacement but the interval depends on conditions at the site and must be determined by site personnel. The transmitters have over temperature detectors, but prolonged operation at high temperature will degrade reliability. Periodic checks of inlet to outlet temperature rise is a

convenient way to detect a decrease in cooling due to filter clogging, without the need for visual inspection.

5.2 Cooling Systems:

To minimize contamination problems and guarantee the optimum operating temperature, closed loop cooling systems are highly recommended. These systems circulate the air through the transmitter and an air-to-liquid heat exchanger. The liquid cooling loop is circulated to cooling units located outdoors. The objective is to maintain a constant air temperature in the transmitter's closed air loop which is slightly below room temperature, but not cold enough to cause condensation problems. The best way to protect your transmitter investment is maintain correct operating temperatures and keeping its interior clean.

5.2.1 Forced Air Systems:

When transmitter cooling is entirely by forced air and external fans are used to assist in air circulation, it is important to make sure the assisting fans do not compete with the transmitter fans. Assisting fans must provide a greater air flow than the total air flow through the transmitter would be if its fans were not assisted. When the exhaust air is ducted to the outside and the intake air is obtained from the room, the preferred location of assisting fans is at the room air intake. Such fans must be rated to provide a positive pressure in the room when the transmitter's fans are operating. This positive pressure will assist the transmitter's fans and when the intake air is adequately filtered, minimize infiltration of dust and insects. If an assisting fan is installed in the exhaust duct, it must provide a negative pressure at the transmitter's exhaust ports when the transmitter's fans are operating.

5.3 Thermal Baffles:

When the intake air is obtained from the room and the exhaust air is returned to the same room, a thermal baffle must be used to ensure the heated exhaust air is not returned directly to the cooling air intake ports. In extreme cases, a thermal runaway can occur if this precaution is not observed.

6 MAINTENANCE AND REPAIR

A good site should be equipped with a work space, appropriate tools and test equipment, but the most important link in the chain is the site technician. He must have formal training in modern solid state electronics as well as the transmitter itself. Nautel offers training on the various models it sells and includes comprehensive handbooks that guide the tech through many of the actions he may need to take. We recommend that anyone expected to maintain our transmitters attend the Nautel training course.

Nautel transmitters are designed with electronic fault latches that identify and store the conditions just before shutdown. These must be recorded before any attempt is made at system reset. The handbook identifies the causes for the various fault alarm indications and should be consulted before taking any action. This simple step can avoid serious fault propagations that a hasty attempt to reset may cause.

When repairs are required, good workmanship and careful attention to detail are vital. If this is not available at the site, the spares and maintenance philosophy must reflect this. For example, it may be more economical in the long run to spare higher level modules than individual FET's if the site staff cannot accurately determine what parts have failed and properly replace them. Modern solid state transmitters are more complex than their predecessors, and improper repair activity may turn a relatively minor fault into a degenerative spiral and an eventual service call.

Often overlooked in the field are the necessary electrostatic discharge (ESD) protection measures for replacing FETs or ICs.

External connections and ground rods do not last forever. They will need to be periodically checked for the effects of corrosion and replaced as they become suspect.

7 FOREIGN MATTER

While it sounds unlikely, we have found snakes (remains) fatally close to the DC bus and tools left in damaging situations. Vigilance in keeping the site clean is worthwhile to ensure uninterrupted operation.

Transmitter buildings and tuning huts should be made as rodent proof as possible. Mice can enter the equipment and rats have been known to chew on AC wiring and other insulation. If food is consumed on site, be sure to clean up and avoid attracting rodents.

8 SAFETY

It is important for you to read the safety section of the handbook and to take the cautions and warnings seriously.

On equipment supplied with a keyed interlock system, it is mandatory that these are used and not defeated by using a duplicate set of keys. This system, properly used, will make it impossible to enter the cabinets without first removing primary AC power and grounding the RF output terminal of the transmitter. The antenna must be grounded before working on the transmitter, because lightning or other transmitters could energize "off" equipment. Using a ground wand on the antenna terminal, as a supplement to the interlock ground, is good practice.

Always measure before touching. Stored energy or turning off the wrong disconnect can be detected harmlessly if you measure first. Ordinary multimeters are not recommended for measuring AC line voltages. Accidents, such as having the meter set to ohms or amps, can put a short on the AC line and result in serious burns from the ensuing arc. There are non-contacting test probes available from several sources (Fluke, Ideal) as well as meters intended for measuring line voltages safely (Teagam).

The transmitter has an emergency power off (EPO) switch. Staff should be familiar with its location and operation. The site will also have an AC power disconnect for the transmitter and these should be well labelled. Installers should identify these and confirm their operation.

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NAUTEL SITE EVALUATION CHECKLIST

The following checklist should be used to evaluate an AM or Beacon solid state transmitter site.

		YES = ☐
1.)	Is there a ball gap at the antenna base?	☐
2.)	Is the diameter of the spark ball spheres a minimum of 37.5 mm?	☐
3.)	Is the spark ball's surface free of arcing/pitting?	☐
4.)	Is the spark ball's air gap set properly?	☐
5.)	Was the site's altitude considered when establishing spark ball's air gap?	☐
6.)	Are a minimum of four ground rods installed at the antenna?	☐
7.)	Is there a static drain choke at antenna?	☐
8.)	Is there a DC blocking capacitor between antenna and transmitter?	☐
9.)	Is the RF feed coaxial cable buried under the antenna radials?	☐
10.)	Do the AC power wiring and RF feed cable enter the building at the same point?	☐
11.)	Are a minimum of four ground rods installed as the station reference ground?	☐
12.)	Is a single ***common point*** used as the connection to the station reference ground?	☐
13.)	Is the RF feed cable's outer conductor connected to the ***common point*** ground?	☐
14.)	Are shunt type MOV line suppressors installed?	☐
15.)	Are the MOVs installed where the AC power wiring enters the building?	☐
16.)	Are the MOVs grounded to the ***common point*** ground?	☐
17.)	Is a shielded, isolation transformer used to interface the AC power source?	☐
18.)	Is the transformer grounded to the ***common point*** ground?	☐
19.)	Are all connections to the ***common point*** ground; short, low inductance straps?	☐
20.)	Is a series type line transient suppressor installed?	☐
21.)	Is a line transient suppressor installed at the AC power entrance?	☐
22.)	Is the transmitter building shielded?	☐
23.)	Do all electrical wires pass through ferrite toroids before they enter the transmitter?	☐
24.)	Does the RF feed cable pass through a ferrite toroid before it enters the transmitter?	☐
25.)	Is this the only transmitter radiating at a given time?	☐
26.)	Is an AC power EMI filter installed?	☐
27.)	Has the antenna and transmission line system been carefully inspected?	☐
28.)	Has the antenna and transmission line system been 'Hipot' tested?	☐
29.)	Is an adequate cooling system in place?	☐
30.)	Is the cooling system a closed loop, air to chilled fluid system?	☐
31.)	Has adequate air flow been provided?	☐
32.)	Is the air flow direction correct?	☐
33.)	Is intake air adequately separated from exhaust air, to avoid thermal runaway?	☐
34.)	Are air filters provided?	☐
35.)	Are the air filters clean?	☐
36.)	Does the impedance of the antenna system match the transmitter's RF output?	☐
37.)	Is a dummy load (rated at twice the transmitter's rated carrier level) on-site?	☐
38.)	Does the impedance of the dummy load match the transmitter's RF output?	☐
39.)	Does the site have an adequately equipped repair area with proper tools?	☐
40.)	Has electrostatic discharge (ESD) been considered in the work area?	☐
41.)	Does the site have adequate test equipment?	☐
42.)	Is there trained technical staff on site to maintain the equipment?	☐
43.)	Has the technical staff attended a Nautel training session?	☐
44.)	Is a record log book available to note the faults experienced?	☐
45.)	Are Nautel technical maintenance manuals in evidence at the site?	☐

RESULTS (QUANTITY of YES's) ____



NAUTEL SITE EVALUATION CHECKLIST

The following checklist should be used to evaluate an FM solid state transmitter site.

		YES = ☐
1.)	Is there a 2nd harmonic stub at the output of the transmitter?	☐
2.)	Do the AC power wiring and RF feed cable enter the building at the same point?	☐
3.)	Are a minimum of four ground rods installed as the station reference ground?	☐
4.)	Is a single ***common point*** used as the connection to the station reference ground?	☐
5.)	Is the RF feed cable's outer conductor connected to the ***common point*** ground?	☐
6.)	Are shunt type MOV line suppressors installed?	☐
7.)	Are the MOVs installed where the AC power wiring enters the building?	☐
8.)	Are the MOVs grounded to the ***common point*** ground?	☐
9.)	Is a shielded, isolation transformer used to interface the AC power source?	☐
10.)	Is the transformer grounded to the ***common point*** ground?	☐
11.)	Are all connections to the ***common point*** ground; short, low inductance straps?	☐
12.)	Is a series type line transient suppressor installed?	☐
13.)	Is a line transient suppressor installed at the AC power entrance?	☐
14.)	Is the transmitter building shielded?	☐
15.)	Do all electrical wires pass through ferrite toroids before they enter the transmitter?	☐
16.)	Does the RF feed cable pass through a ferrite toroid before it enters the transmitter?	☐
17.)	Is this the only transmitter radiating at a given time?	☐
18.)	Is an AC power EMI filter installed?	☐
19.)	Has the antenna and transmission line system been carefully inspected?	☐
20.)	Has the antenna and transmission line system been 'Hipot' tested?	☐
21.)	Is an adequate cooling system in place?	☐
22.)	Is the cooling system a closed loop, air to chilled fluid system?	☐
23.)	Has adequate air flow been provided?	☐
24.)	Is the air flow direction correct?	☐
25.)	Is intake air adequately separated from exhaust air, to avoid thermal runaway?	☐
26.)	Are air filters provided?	☐
27.)	Are the air filters clean?	☐
28.)	Does the impedance of the antenna system match the transmitter's RF output?	☐
29.)	Is a dummy load (rated at 110% the transmitter's rated carrier level) on-site?	☐
30.)	Does the impedance of the dummy load match the transmitter's RF output?	☐
31.)	Does the site have an adequately equipped repair area with proper tools?	☐
32.)	Has electrostatic discharge (ESD) been considered in the work area?	☐
33.)	Does the site have adequate test equipment?	☐
34.)	Is there trained technical staff on site to maintain the equipment?	☐
35.)	Has the technical staff attended a Nautel training session?	☐
36.)	Is a record log book available to note the faults experienced?	☐
37.)	Are Nautel technical maintenance manuals in evidence at the site?	☐

RESULTS (QUANTITY of YES's)... ____

APPENDIX A
LIGHTNING INFORMATION

A1 INTRODUCTION

This appendix contains extracts from authoritative papers/books. They are intended to provide the reader with additional lightning related data.

A1.1 Incidence of Thunderstorms:

Figure A-1 of this appendix is a world-wide map showing the average number of days with thunderstorms per year.

A1.2 Lightning Rise Time:

Recent studies indicate the rise time for lightning strikes is much shorter than previously thought. The following is an extract from *Protection of Electronic Circuits from Overvoltages* - Ronald B. Standler, Wiley 1989.

Rise times of the order of 1 µs are commonly reported in the older literature. These values for the rise time are too large, owing to inadequate bandwidth of recording devices (e.g, tape recorders, oscilloscopes) and electronic signal processing circuits. Even when oscilloscopes with adequate bandwidth were used, the sweep rate was usually set to a relatively slow rate in order to capture most of the return stroke waveform. Therefore, data on submicrosecond rise times could not be obtained. Recent measurements with faster electronics, rapid analog-to-digital data conversion, and storage in semiconductor digital memories have revealed rise times on the order of 0.1 µs. These data may still suffer from limited bandwidth.

For practical reasons, direct measurements of lightning currents are usually done with instruments located on tall towers or tall buildings that are struck by lightning many times during each year. However, the presence of the tall object may alter the properties of the lightning. In particular, many of the lightning events are upward-propagating discharges that are not preceded by a stepped leader.

Some of the major parameters in cloud-to-lightning flashes are summarized in Table A-1. The combination of a 20 kA peak current and a 0.2 µs rise time implies a value of *dI/dt* of 10^{11} A s^{-1}. This large value of *dI/dt* implies that transient protection circuits must use radio frequency design techniques, particularly considerations of parasitic inductance and capacitance of conductors, which are discussed in Chapter 15.

Although peak currents of the order of 10 kA in cloud-to-ground lightning are certainly impressive, one should recognize that the bulk of the charge transferred by a lightning flash occurs during the continuing currents, which are usually between 50 and 500 A, for a duration of between about 0.04 and 0.5 seconds. Continuing current is responsible for much of the damage by direct strikes, including arc burns on conductors and forest fires (Fuquay et al, 1972; Brook et al, 1962; Williams and Brook, 1963).

Table A-1 Major Parameters in Cloud-to-Ground Lightning Flash

PARAMETER	TYPICAL VALUE	WORST-CASE VALUE
Peak return stroke current	20 kA	200 kA
Total charge transfer	20C	300C
Rise time of return stroke	0.2 µs (?)	
Maximum dI/dt of return stroke	10^{11} A/s	

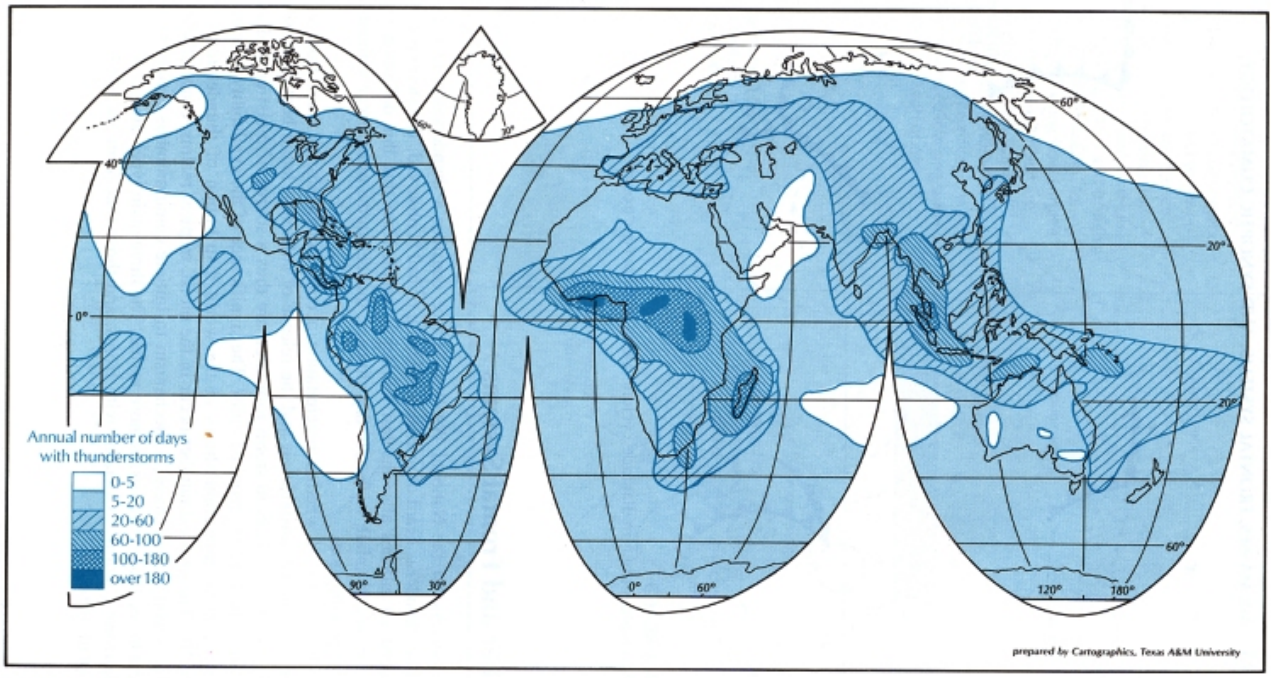


FIGURE 10.10
World distribution of thunderstorms.
Source: After S. D. Gedzelman, *The Science and Wonders of the Atmosphere*. (New York: John Wiley & Sons, 1980), 333.

Figure A-1 Average Annual World-Wide Thunderstorm Days

APPENDIX B
AIR SPARK GAP INFORMATION

B1 INTRODUCTION

This appendix contains information, in the form of graphs, which will assist in determining the proper air gap setting of antenna spark balls or other air spark gaps in the RF transmission system. There is two of each graph. One has been completed using example site information and the other is unmarked. The unmarked graph is to be completed by the person responsible for setting the spark gap at a site.

EXAMPLE SITE:

RF Carrier Level	- 30 kW
Antenna Impedance	- 200 Ohms
Spark Ball Diameter	- 37.5 mm
Site Altitude	- 4000 Feet

B2 BREAKDOWN VOLTAGE RELATIVE TO FREQUENCY

Figure B-1 depicts a graph that plots the ratio of high frequency breakdown voltage to static breakdown voltage as a function of frequency for a uniform field air gap. The static breakdown voltage for air is nominally 30 kV/cm (75 kV/inch). The plot in Figure B-1 indicates the breakdown voltage in air for 1.0 MHz is reduced and is approximately 80% of the static breakdown voltage. The ratio for the entire AM broadcast frequency band is in the 80% range, therefore, the graph showing the breakdown voltage for air at 1.0 MHz can be used at AM broadcast sites.

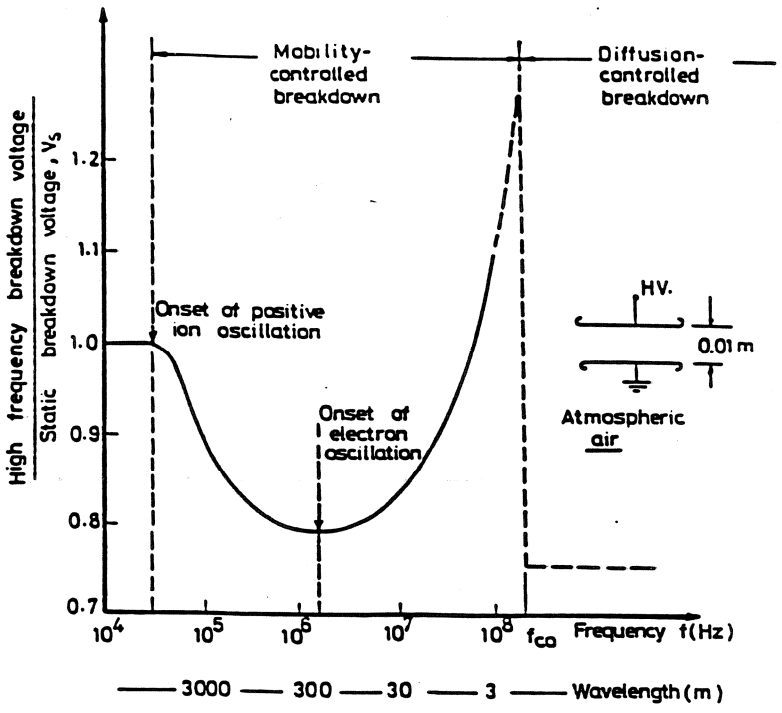


Figure B-1 High Frequency Versus Static Breakdown Voltage Ratio

B3 PEAK VOLTAGE VERSUS RF CARRIER LEVEL

Figure B-2 contains a graph that allows determination of the peak voltage to be expected at the antenna input (across the spark balls). This is determined by plotting the maximum RF carrier power to be transmitted against the resistive impedance of the antenna. ***Note*:** the antenna impedance must be obtained from antenna design records. This graph assumes the worst case, which is 140% modulation and a VSWR of 1.5:1. These assumptions will ensure arcing does not occur on modulation peaks, when the VSWR is within acceptable limits. The top graph [Figure B-2(a)] has been plotted using the figures tabulated for the example site (30 kW RF carrier level and an antenna impedance of 200 ohms). The bottom graph [Figure B-2 (b)] has been provided for customer use.

B3.1 Determination of Antenna Peak Voltage:

Obtain the antenna impedance from antenna design records, and if necessary, draw a line representing its impedance on the graph. Enter the graph with the RF carrier level to be radiated and draw a vertical line on the 'X' axis, at the corresponding point on the ***RF carrier power in kilowatts*** scale. Determine the peak voltage in kilovolts (kV_{PEAK}). Draw a horizontal line on the 'Y' axis where the vertical line representing the RF carrier level intersects the line representing the antenna impedance and read the ***peak voltage*** (kV_{PEAK}) scale.

B4 AIR GAP SPACING FOR UNIFORM FIELD

Figures B-3 and B-4 contain graphs which allow determination of the air gap spacing for a uniform field at a frequency of 1.0 MHz, when the peak voltage (kV_{PEAK}) is known. Figure B-3 is intended for use at higher peak voltages (up to 50 kV_{PEAK}), while Figure B-4 will provide a more accurate reading at lower peak voltages (up to 13 kV_{PEAK}). The air gap spacing is determined by plotting the maximum peak voltage against the line representing the air breakdown voltage at 1.0 MHz.

Note: kV_{PEAK} is determined as detailed in paragraph B3.1. The top graph of both figures has been plotted using the peak voltage calculated for the example site (30 kW RF carrier level and an antenna impedance of 200 ohms).

B4.1 Determination of Uniform Field Air Gap:

Enter the appropriate graph (Figure B-3 or B-4) with the peak voltage (kV_{PEAK}) determined in paragraph B3.1 and draw a horizontal line on the 'Y' axis, at the corresponding point on the ***kV($_{Peak}$) breakdown voltage*** scale. Determine the uniform field air gap spacing in millimetres (mm). Draw a vertical line on the 'X' axis where the horizontal line representing kV_{PEAK} intersects the line representing the air breakdown voltage at 1.0 MHz and read the ***uniform field gap spacing*** scale.

B5 AIR GAP CORRECTION FACTOR FOR SPARK BALL DIAMETER

Figure B-5 contains a graph that provides a correction factor that is determined by the diameter of the spark balls when the uniform field air gap spacing is known. The spark ball diameter correction factor is determined by plotting the uniform field air gap spacing against the line representing the diameter of the spark balls in use. *Note:* the uniform field air gap spacing is determined in paragraph B4.1. The top graph has been plotted using the uniform field air gap spacing for the example site (30 kW RF carrier level and an antenna impedance of 200 ohms).

NOTE

Spark balls with a diameter of 37.5 to 50 mm provide a uniform field for air gap settings of 5.0 mm or less. If a larger gap is required, the gap spacing multiplier will provide a field enhancement for the curvature of the balls. The field enhancement factors for other geometries can be determined, but are not recommended for use.

B5.1 Determination of Spark Ball Diameter Correction Factor:

Enter the bottom graph in Figure B-5 with the uniform field air gap spacing determined in paragraph B4.1 and draw a vertical line on the 'X' axis at the corresponding point on the ***uniform field gap spacing*** scale. Determine the air gap correction factor for the diameter of the spark balls in use. Draw a horizontal line on the 'Y' axis where the vertical line representing the uniform field air gap spacing intersects the line representing the diameter of the spark balls in use and read the correction factor on the ***multiply uniform field gap spacing*** *by* scale.

B5.2 Air Gap Spacing Corrected For Spark Ball Diameter:

Determine the field enhanced air gap spacing (air gap spacing which has been corrected for the diameter of the spark balls in use) by multiplying the uniform field air gap spacing obtained in paragraph B4.1 by the correction factor obtained in paragraph B5.1.

B6 AIR GAP CORRECTION FACTOR FOR ALTITUDE

Figure B-6 contains a graph that provides a correction factor that is determined by the site altitude. The altitude correction factor is determined by plotting the site altitude against the line representing the correction factor over the full altitude scale. *Note:* the altitude of the site must be obtained from site records. The top graph has been plotted using the altitude of the example site (4000 feet).

B6.1 Determination of Altitude Correction Factor:

Enter the bottom graph in Figure B-6 with the site altitude and draw a vertical line on the 'X' axis at the corresponding point on the ***altitude in thousands of feet*** scale. Determine the altitude correction factor. Draw a horizontal line on the 'Y' axis where the vertical line representing the altitude intersects the line representing the altitude correction factor and read the correction factor on the ***multiply field enhanced gap spacing by*** scale.

B7 FINAL AIR GAP SETTING FOR ANTENNA SPARK BALLS

Determine the final air gap setting for antenna spark balls by multiplying the field enhanced air gap setting, which was obtained in paragraph B5.2; by the altitude correction factor from paragraph B6.1.

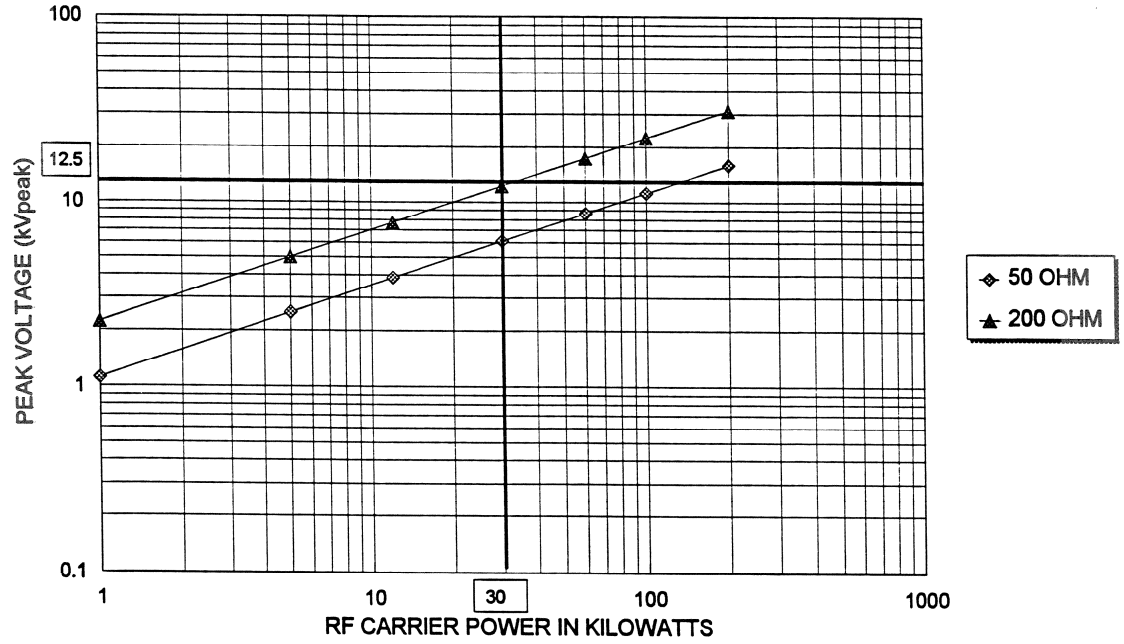
NOTE

The air gap calculations do not contain provision to set the gap at a larger setting than is absolutely essential. The only gap increasing factors that were considered, were the simultaneous worst case condition of 140% modulation peaks and a VSWR of 1.5:1, the geometry of the spark gap balls and the site altitude.

It is a natural tendency to increase the spark gap setting to avoid nuisance trips caused by weather conditions, insects, etc. It is Nautel's contention that minimizing risks to the transmitter and associated electronics is the highest priority. For maximum protection of the transmitter, it is advisable to be aggressive and set the gap to the minimum setting that will permit normal operation without arcing.

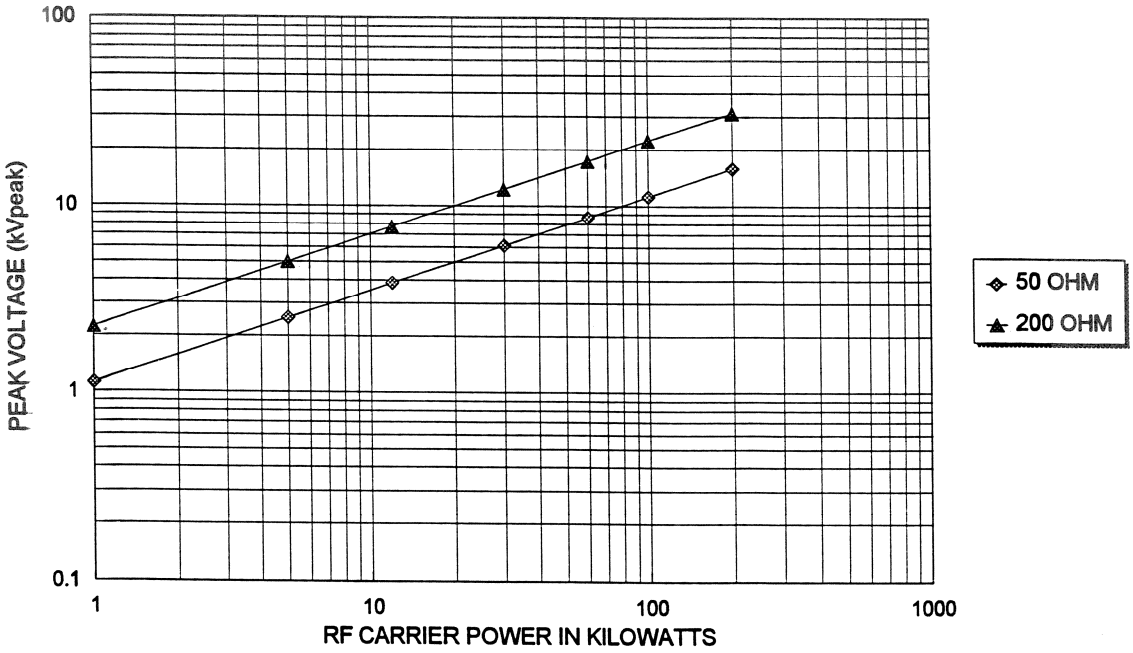
B8 SOURCE FOR ANTENNA SPARK BALLS

Nautel offers an air gap spark ball assembly that uses carbon balls. Carbon balls are superior to other metal balls, because they are not damaged by lightning currents. This helps to improve the repeatability of the gap breakdown voltage. The spark balls can be mounted at the base of the antenna and they should be installed using very low inductance/ resistance connections. It is also advisable to protect the gap from rain. It may also be necessary to enclose it with a non-conducting screen material to keep out insects and other creatures. Appendix 'C' lists other suppliers and provides extracts from their data sheets.



Worst Case Assumptions of 140% Modulation with 1.5:1 VSWR

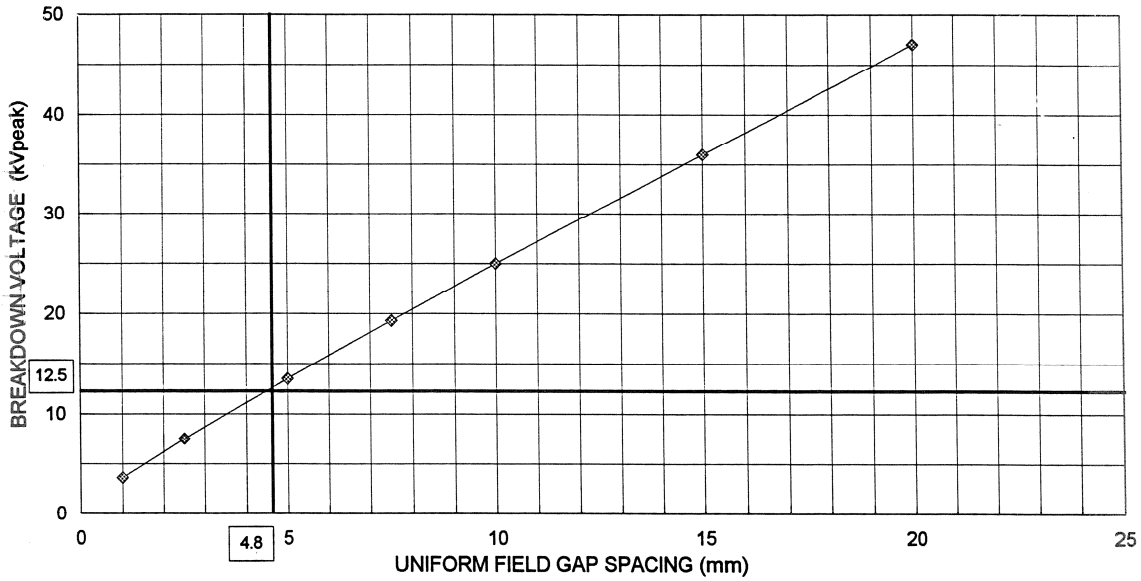
(a) **EXAMPLE:** RF Carrier Power = 30 kW, Antenna Impedance = 200 Ohms
Calculated Peak Voltage = 12.5 kV_{PEAK}



Worst Case Assumptions of 140% Modulation with 1.5:1 VSWR

(b) **CUSTOMER USE:** Enter RF Carrier Power, Antenna Impedance, calculate Peak Voltage

Figure B-2 Peak Voltage Versus RF Carrier Power



EXAMPLE: Established Peak Voltage = 12.5 kV_{PEAK}
Trace = Breakdown Voltage for Air at 1.0 MHz
Calculated Uniform Field Gap Spacing = 4.8 mm

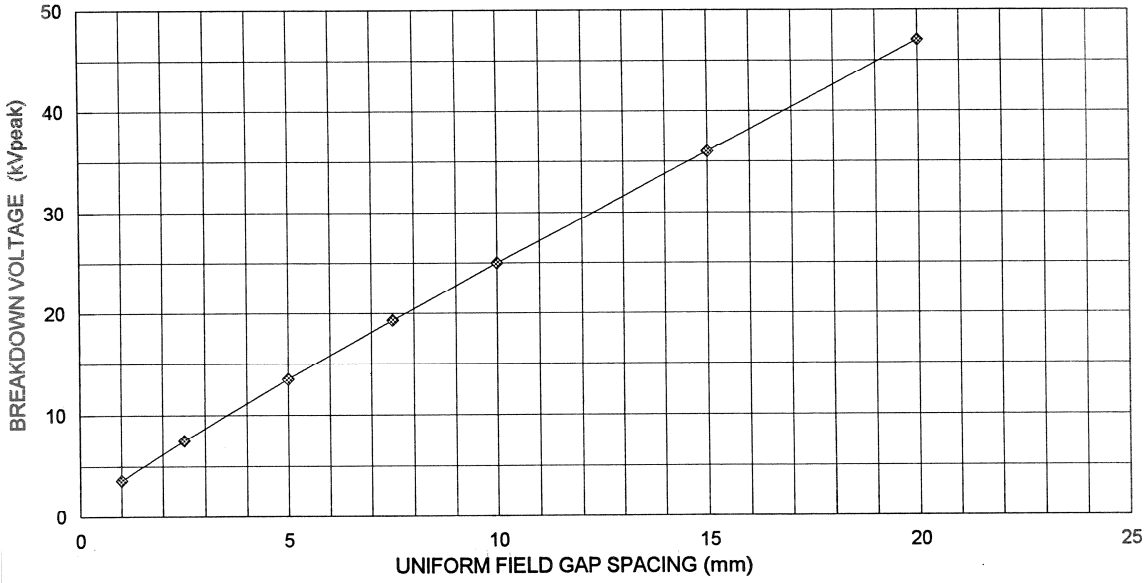
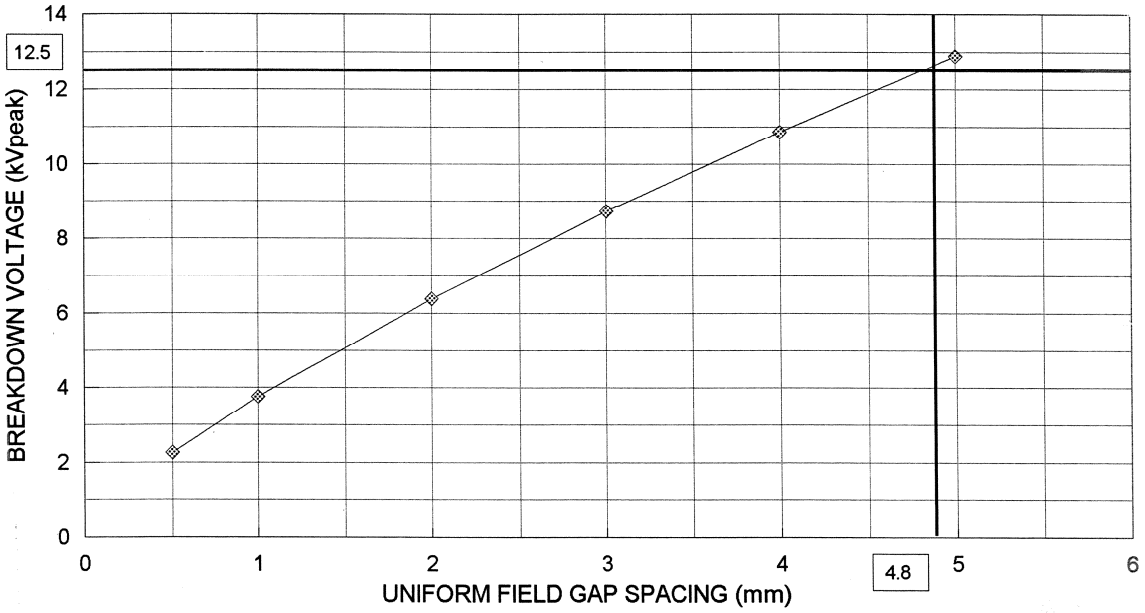


Figure B-3 Determination of Uniform Field Gap Spacing (High Volts - Up to 50 kV_{PEAK})



EXAMPLE: Established Peak Voltage = 12.5 kV_{PEAK}
Trace = Breakdown Voltage for Air at 1.0 MHz
Calculated Uniform Field Gap Spacing = 4.8 mm

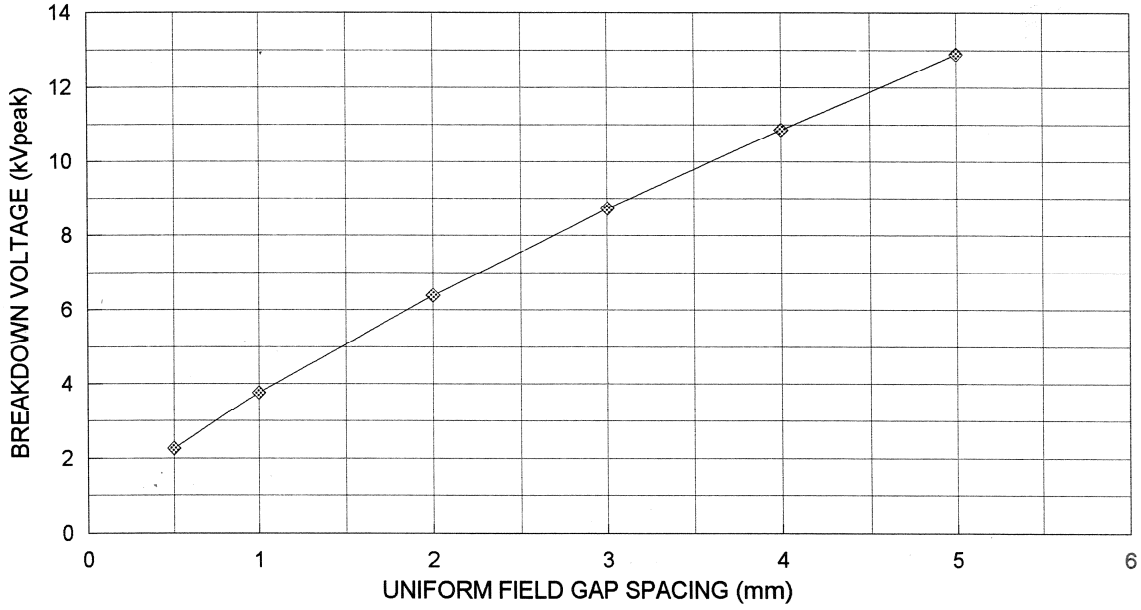
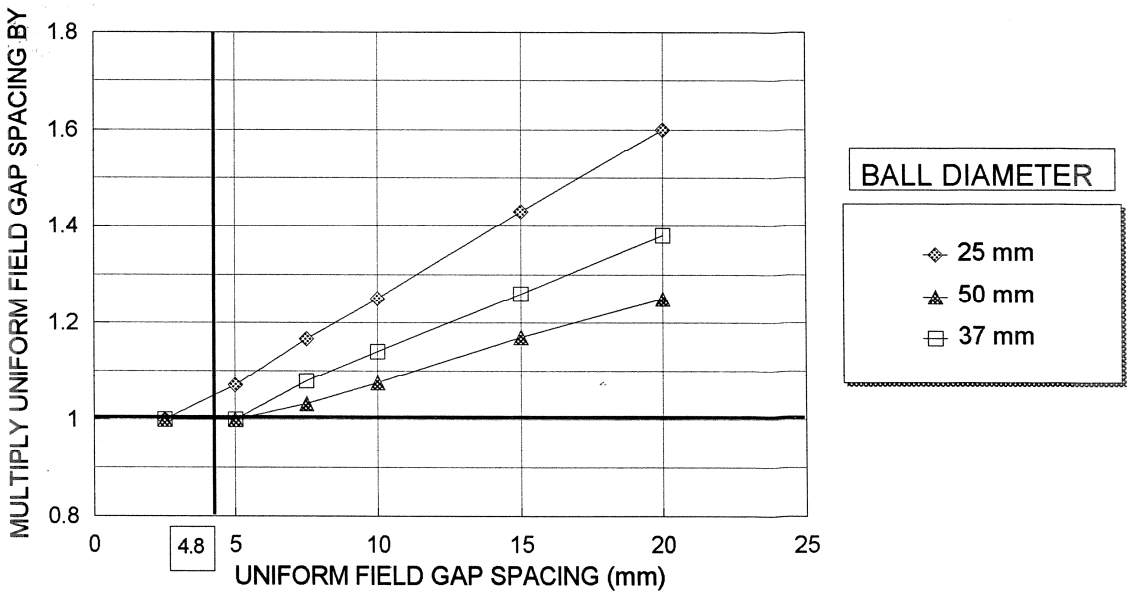


Figure B-4 Determination of Uniform Field Gap Spacing (Low Volts - Less Than 14 kV_{PEAK})



EXAMPLE: Established Uniform Field Gap Spacing = 4.8 mm
When Ball Diameter is 37 mm, Calculated Field Enhancement Correction Factor = 1.0

Field Enhanced Air Gap When Uniform Field Air Gap is 4.8 mm = 4.8 mm x 1.0 = 4.8 mm

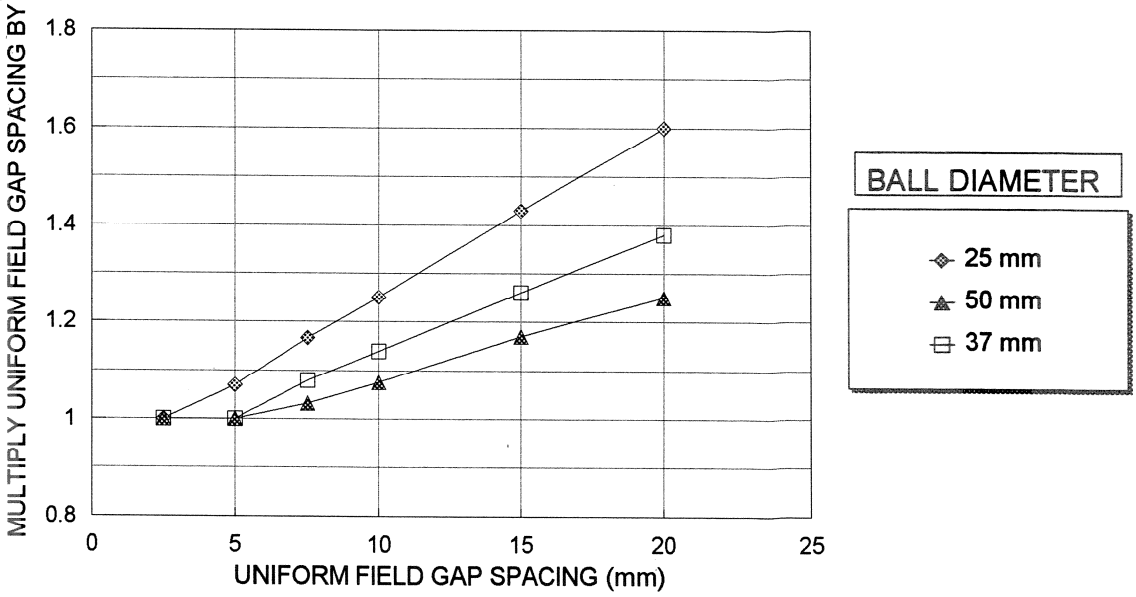
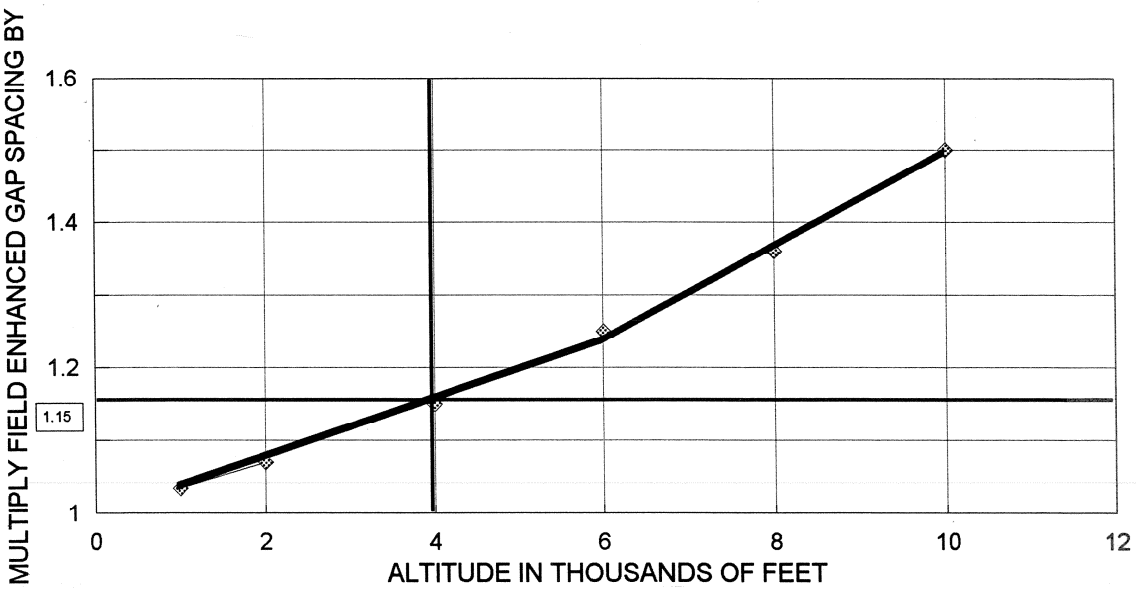


Figure B-5 Spark Ball Diameter Correction Factor



EXAMPLE: Site Altitude = 4000 Feet
Calculated Altitude Correction Factor = 1.15

Final Air Gap Setting When Field Enhanced Air Gap is 4.8 mm = 4.8 mm x 1.15 = 5.5 mm

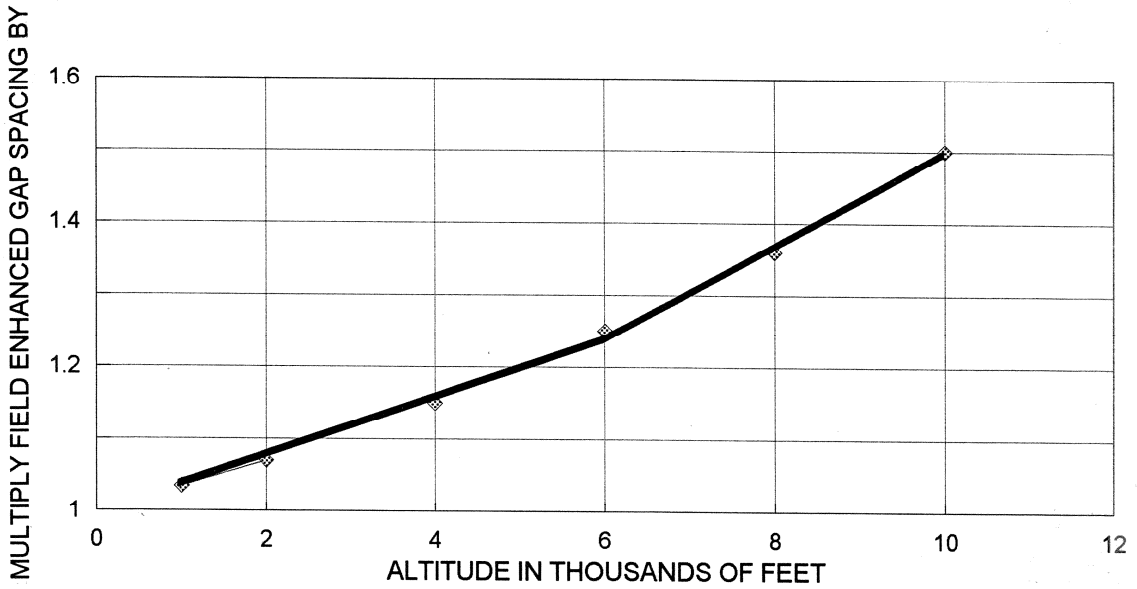


Figure B-6 Altitude Correction Factor

APPENDIX C
SPARK BALL DATA/SOURCES



SPHERE SIZES
0.2" TO 22"
0.5CM TO 56CM



TOROIDS SIZES
0.75" TO 52"
1.9CM TO 132CM

Geometrically designed to reduce excessive voltage gradients at connecting points and other areas needing shielding or balancing of electrostatic fields. Also an increase withstand voltage by improved grading and minimize corona. Many diameters are to IEC publication 52 standard metric sizes.

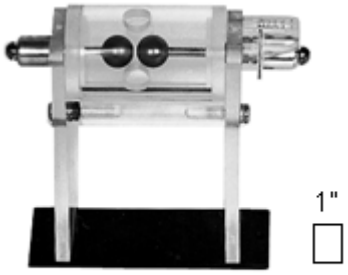
Many of Ross Engineering's line of toroids, spheres, and corona nuts have been designed to meet metric dimensions. The Ross toroids are made of aluminum while most spheres are made of either hollow aluminum or solid non-melting carbon with other materials optional. A satin finish is standard with a high polish finish available. Aluminum toroids and spheres are used to minimize corona and for adjusting voltage gradients on long stacks of high voltage components. Spheres are also used for spark gaps and corona eliminating terminations. Carbon spheres are desirable where high current arcing is involved since they do not melt or develop pits or projections but tend to remain a smooth surface. Also, with the presence of slight amounts of Carbon 14, they have a tendency to have more consistent spark-over levels.

Ross Toroids come in two separable halves as standard. A one piece toroid is formed by heliarcing two halves together. Toroids, or hemisphere-toroid configurations, can be used in place of spheres where height is limited. Available toroid diameters range from 10cm to 106.7cm (3.94in to 42in). Mounting holes are optional and other sizes can be provided.

Ross Spheres are available in solid or hollow aluminum, solid carbon, or other materials upon request. Most sizes recommended by the International Electro Technical Commission (IEC) are standard. The aluminum spheres are usually used for limited current spark gaps or for terminations. Diameters of the standard spheres range from 2.5 cm to 50 cm (.98 in to 19.68 in). The non-melting carbon spheres are used for calibrated spark gaps, lightning arresters on antennas, power supply overvoltage, and other transient suppression and high current spark discharge in pulse forming networks. The solid sphere diameters vary from 1 cm to 30.48 cm (.396 in to 12 in).

Ross Corona Nuts are a modification of a sphere or toroid shape and are widely used in moderate high voltage applications. Their recommended operating voltages are up to 300 KV. Diameters of the corona nuts range from .64 cm to 3.8cm (25in to 1.5in).

B-1015



SG-40-H
4-40KV PK

Non-melting carbon spheres and heavy wall aluminum spheres, 0.2" to 22", 0.5cm to 56cm dia. With dust tight transparent covers, 2 kV to 88 kV. Open style to 670 kV. Micrometer type calibrating devices.

Features:
Spark gaps are enclosed in dust tight transparent enclosures with replaceable non- melting carbon spheres, up to 88 kV PK.

Above 88 kV, open style with hollow aluminum spheres is standard.

Applications for these units include over-voltage limiting, voltage measurement, capacitor discharge, and pulse forming.

Horizontal unit housings are removable.

Vertical unit housings are not removable.

Micrometer Vernier adjustment is standard for maximum accuracy on most models.

Economy units without micrometer Vernier adjustment are available as an option.

Insulation to ground is available at standard and optional levels.

Spark gaps to 370 kV, with motor operation available.

ROSS ENGINEERING CORPORATION
540 WESTCHESTER DR., CAMPBELL, CA 95008
VOICE: 408-377-4621, TOLL FREE: 800-654-3205, FAX: 408-377-5182
E-MAIL: info@rossengineeringcorp.com

Clearance Standards
Clearances recommended by the International Electrotechnical Commission (IEC) Publication 52, are standard.

Diameter Standards
International Electrotechnical Commission (IEC) heavy wall hollow is standard in aluminum over 4" in diameter, Solid non-melting carbon alloy is used for diameters of 4" or less, although larger diameters in solid carbon are available. A copy of the latest international high voltage standards, including charts for calibration and spheregap spacing vs. spark-over voltage, is available at extra cost.

Accuracy
Accuracy is approximately ±2% when barometric pressure and temperature conditions are applied (see "Adjustments") and the gap is conditioned by sparkovers until consistent breakdown is reached. Considerable variation may occur over long periods of inactivity if gaps are not conditioned or free ions are lacking or excessive.

Current Limitations
To prevent damaging the precision voltage measurement type sphere-gap surfaces, current should be limited. Less than 5,000 amps discharge PK current and less than the equivalent of approximately 15,000 joules total system energy at 100 microseconds time constant should be used. Correspondingly, less energy should be used at longer time periods. Long time DC and 60 cycle current of 50 milliamps or even more, depending on the total time, are allowable. Usually values of 100,000 ohms or more are inserted in series with precision gaps. Carbon spheres can handle higher currents and longer time Power arcs where metal gaps would be damaged, Current must be limited as to maximum current level and time for required life (see catalog description section for coulomb capacity).

Transient Suppression
Where sphere-gaps are used for transient suppression: some resistance in series can be used in order to provide energy dissipation and to reduce oscillatory action which tends to allow the arc to extinguish too early by creating current zeros. To limit peak current flow, 1 to 2 ohms resistive per KV, possibly more, should be inserted in series with any transient limiting device such as spark-gaps and suppression capacitors, Care must be taken, however, not to have excessive resistance which will limit the clamping effect. 5 to 10 ohms per KV appears to be the upper limit in most cases, usually considerably less than the critical damping values would be.

Interrupt Time Requirements
Where power follow current is available, total sensing and interrupt time should be less than 33-40 milliseconds (2 cycles), An interrupt time of less than 8 to 16 milliseconds (1/2 to 1 cycle) is preferred. This will help to minimize destructive effects, particularly if the current or time can be limited to allow less than 10 to 20 coulombs (amp-seconds), depending on the electrode material and arc spinning arrangement. Carbon and Tungsten alloys have the higher coulomb capacity.

Elevation-Temperature-Pressure Adjustments
Ratings for these spark-gap units are 760 mmHg, 25° C. Derate, approximately 1.5% per 1,000 feet elevation. Pressure and temperature adjustments can be made according to the following formula:

$$Vact=Vntp[(0.386P)/(273+T)]$$

where P is barometric pressure in Torr (mmHg, 0°C) and T is ambient temperature in degrees centrigrade.

See IEC Publication 52 for more accurate correction factors if correction is more than ±5%.

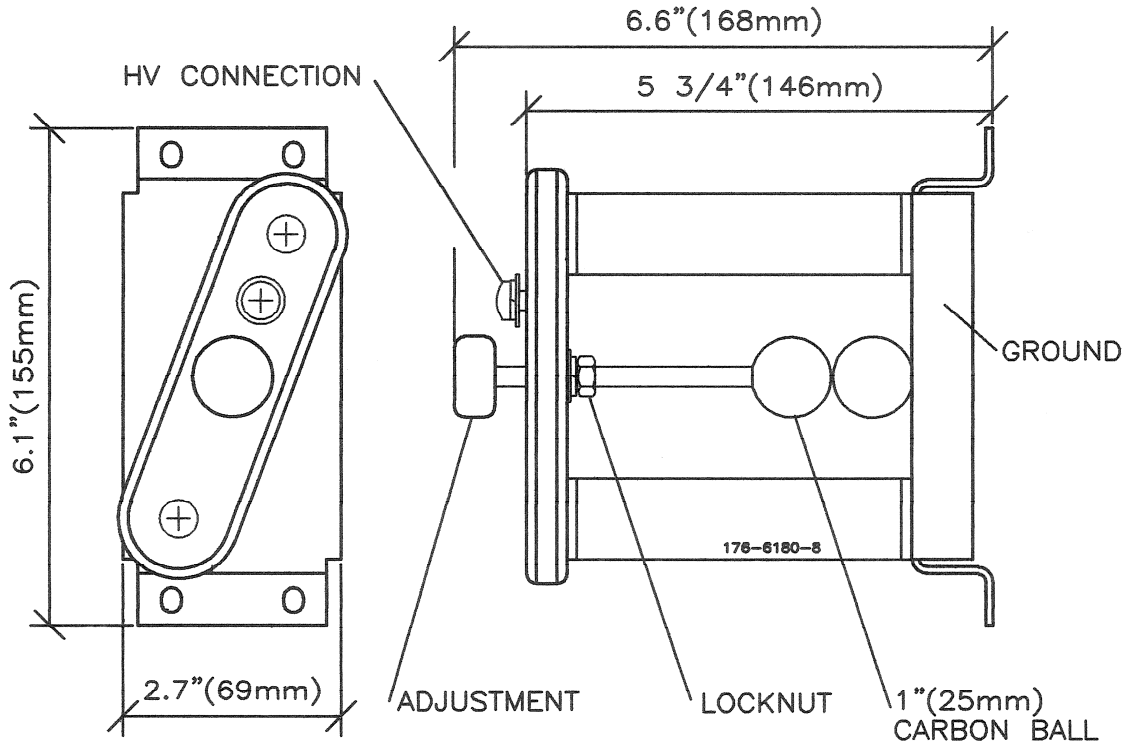
Increased Accuracy
Standard spheres and sphere-gap units contain no added radioactive materials and are not hermetically sealed. The carbon spheres do contain slight amounts of naturally occurring radioactive carbon isotopes. If greater accuracy is required, particularly with close spacings and lower voltages, sparking surfaces can be illuminated with an ultra-violet bulb of at least 35 watts, 1 amp. Accuracy at low voltages can also be improved by inserting radioactive material in the order of 0.2 to 0.6 millicurie in the surface of the spheres. Safety rules must be followed in the handling of radioactive materials.

Options
Some optional features include: calibrated sphere-gap systems with adjustable positioning holder; solenoids for automatic closing; complete current sensing systems to crobar (closing gaps in case of spark-over); motor and air operated units.

Peak Test to Ground
Standard peak test to ground is approximately 120% of maximum sphere spark-over rating or more.

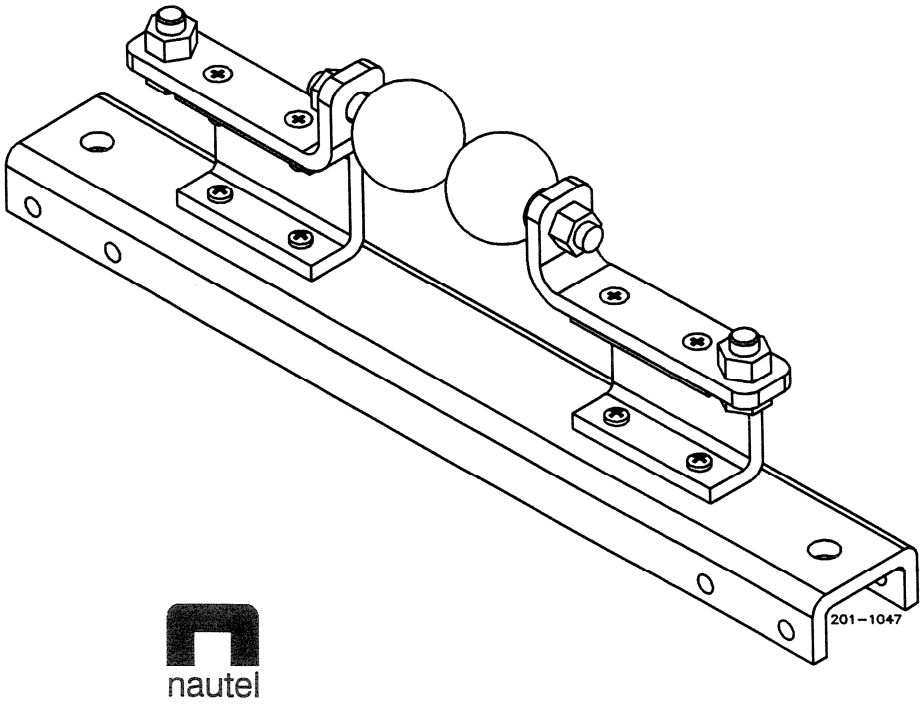
Note: Sphere-gap spark-over will be non-linear at wider spacings for various conditions of AC, DC, polarity, grounding, and proximity of other objects. Consult standards for accurate settings for these conditions.

ROSS ENGINEERING CORPORATION
540 WESTCHESTER DR., CAMPBELL, CA 95008
VOICE: 408-377-4621, TOLL FREE: 800-654-3205, FAX: 408-377-5182
E-MAIL: info@rossengineeringcorp.com



- ADJUSTMENT RANGE 0-3/8" (9.5mm)
- FOR USE IN ENCLOSURE
- MAX V(peak) 25KV (17.7KV RMS)

Figure C-1 176-6180-08 Indoor Spark Gap



- 37.5 mm DIA SOLID CARBON SPHERE
- ADJUSTMENT RANGE 0–20mm
- CORROSION RESISTANT DESIGN
- OPTIONAL WEATHER SHIELD

Figure C-2 NAX181 High Voltage Spark Gap

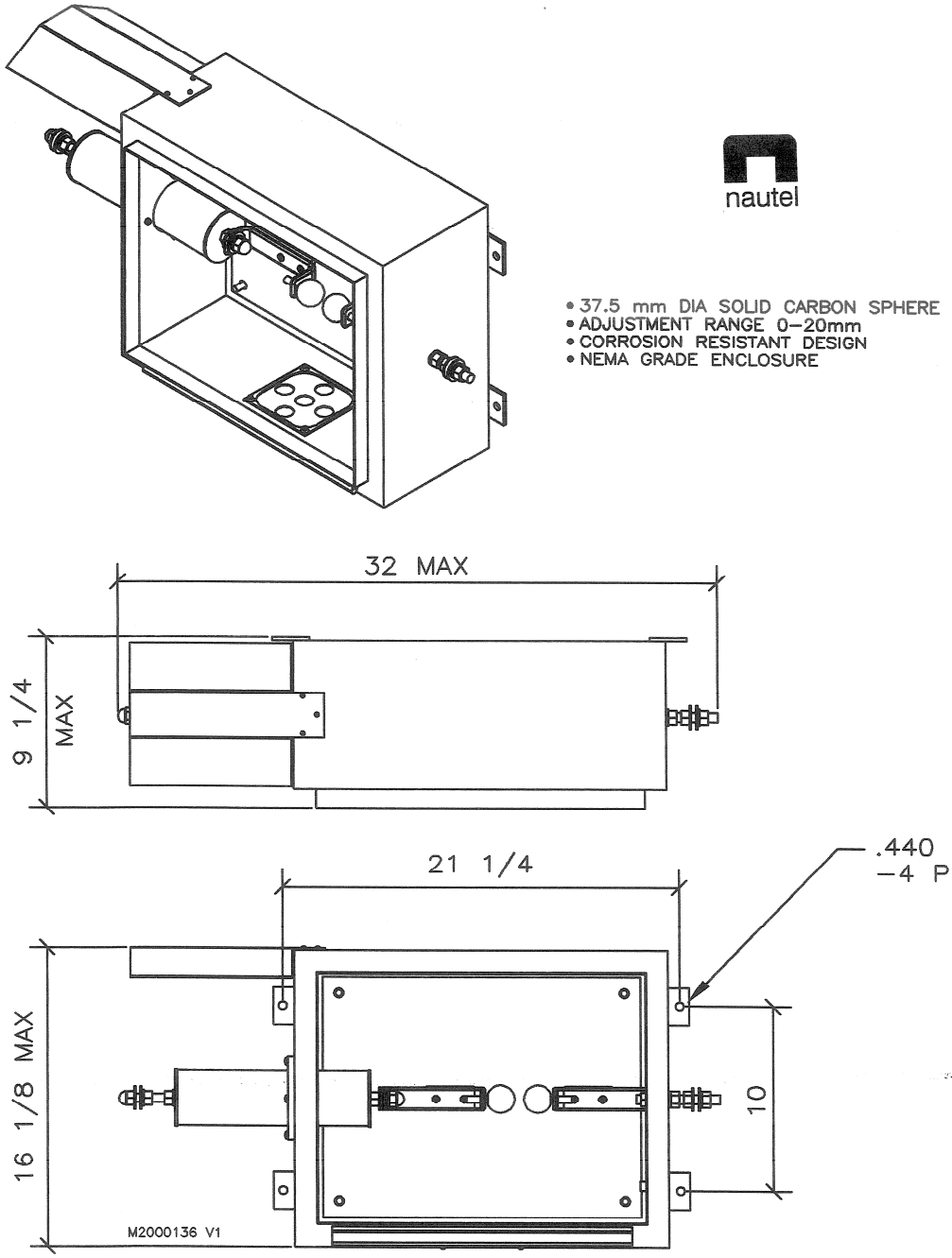


Figure C-3 NAX185 Enclosed High Voltage Spark Gap

APPENDIX D
COMMON POINT GROUNDING RECOMMENDATIONS

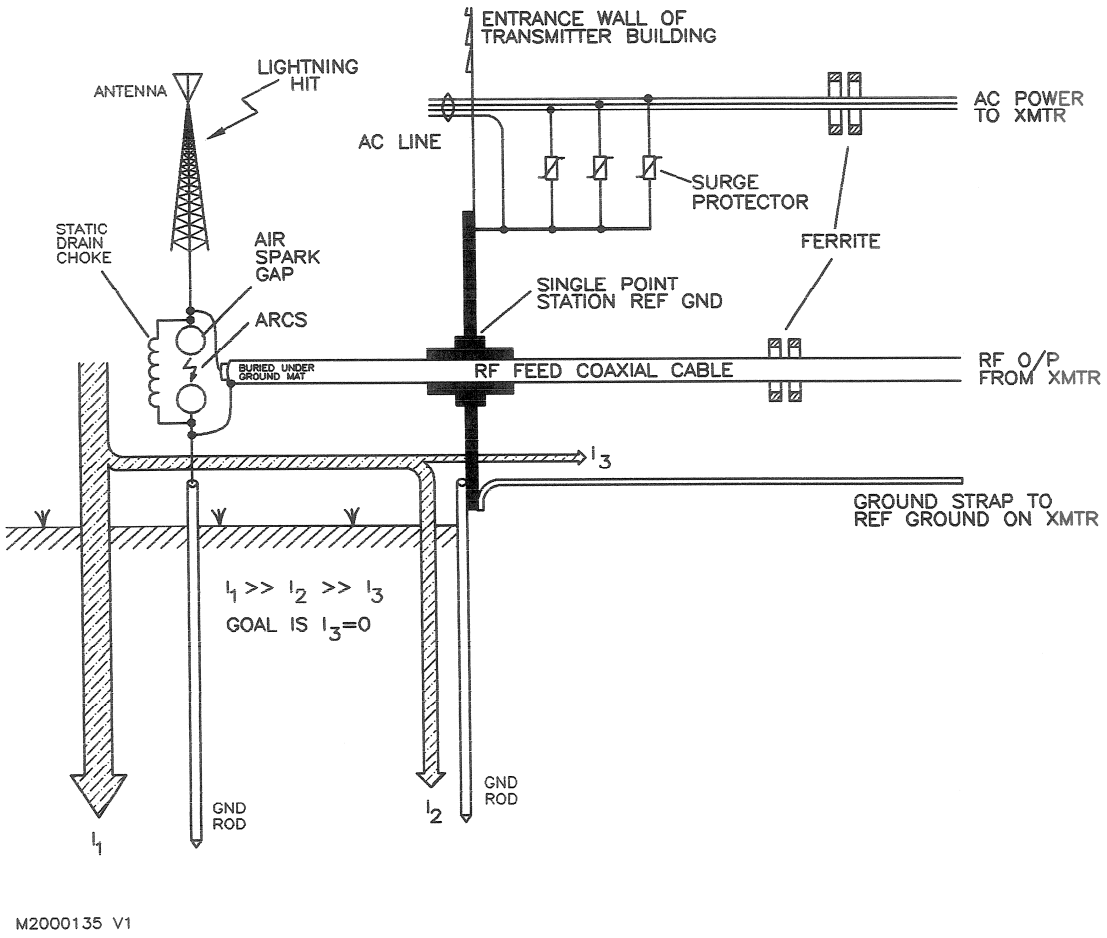


Figure D-1 Simplified Schematic Showing Single Point Ground

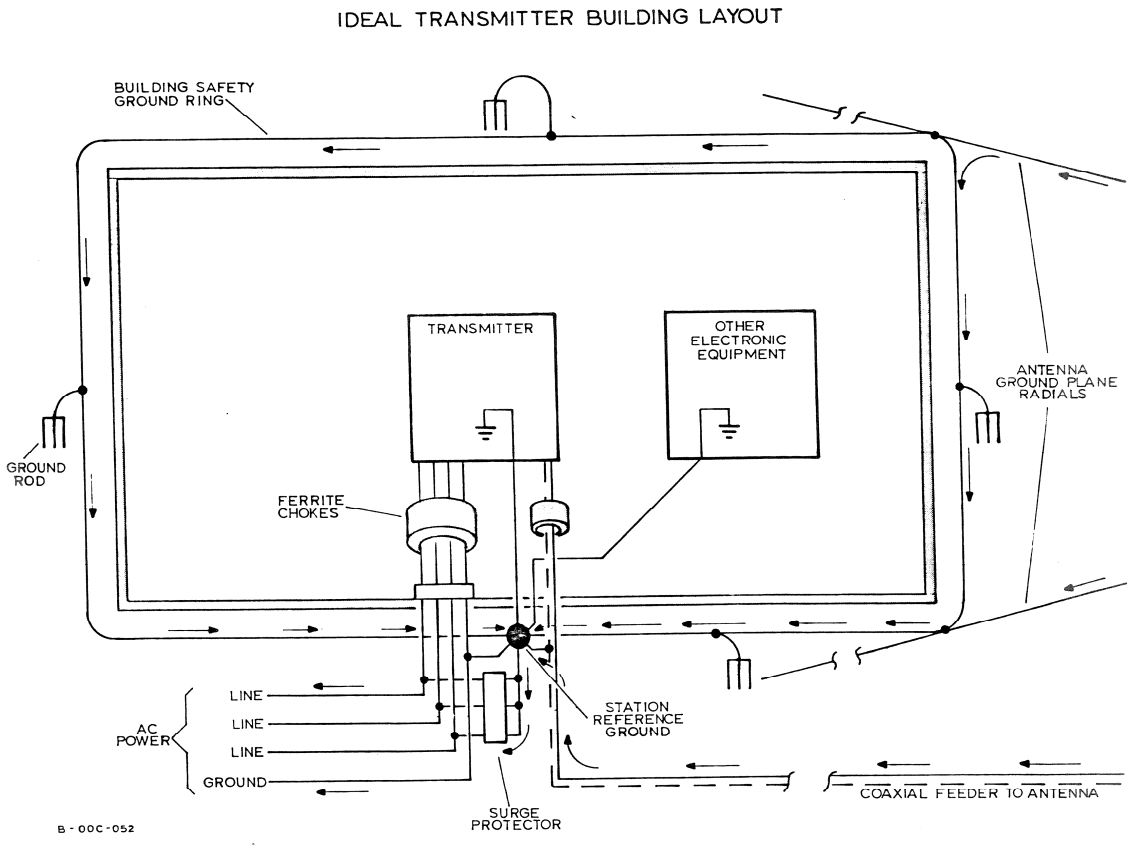


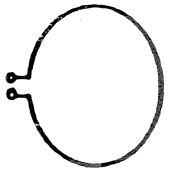
Figure D-2 Ideal Transmitter Building Layout (Electrical Representation)

The adjacent graph allows the reader to calculate the amount of self inductance presented by a straight, round wire at high frequencies. A wire must be as short and as free from bends as is possible to achieve minimum inductance.

i.e.
Since a 2/0 AWG wire has a nominal diameter of 365 mils, it has an inductance of 0.25 µH/ft according to the graph. Each 90-degree bend develops about 0.15 µH of additional inductance. When the wire length and number of 90-degree bends are known, the inductance can be calculated.

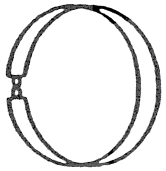
INDUCTANCE OF WIRE LOOPS

6.0 Inch LENGTH of 22AWG



A
1.0 µH

6.0 Inch LENGTH of 0.5



B
0.07 µH



C
0.03 µH



D
<0.01 µH

Self-Inductance of a Straight Round Wire at High Frequencies

CALCULATING INDUCTANCE

Copper Wire

$$L = 0.508l\left[\left(2.303\log_{10}\frac{4l}{d}\right) - 0.75\right]x10^{-2}$$

Copper Strap

$$L = 0.508l\left[\left(2.303\log_{10}\frac{2l}{w+t}\right) + 0.5 + \left(0.2235\frac{w+t}{l}\right)\right]x10^{-2}$$

Where:
L = inductance in µH
l = length in inches
d = diameter in inches
w = width in inches
t = thickness in inches

Figure D-3 Data to Assist in Determination of Ground Wire Inductance

APPENDIX E
STRESS CONTROL AT ELECTRODE/INSULATOR INTERFACE

E1 INTRODUCTION:

Figure E-1 depicts the right and wrong way to control stress at a three-material junction (metal electrode, solid insulator and gas insulator). Figure E-2 depicts a typical bowl type insulator. This type of insulator will increase the tracking distance between a metal conductor and grounded periphery.

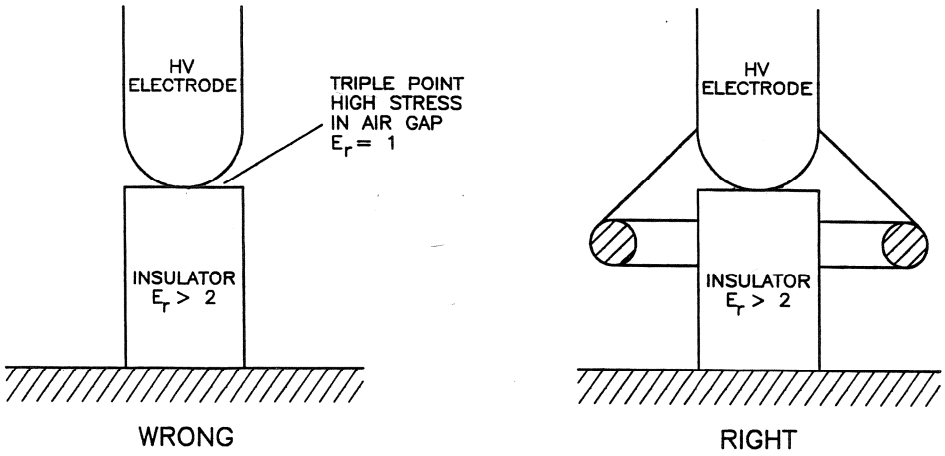


Figure E-1 Stress Control at Electrode/Insulator Interface

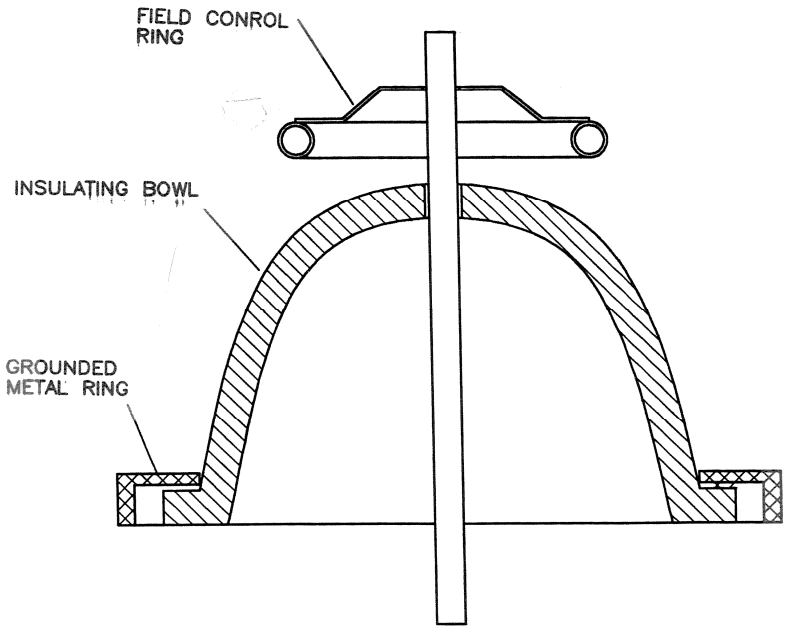


Figure E-2 Typical Feed-Through Bowl Insulator

APPENDIX F
ELECTROMAGNETIC SUSCEPTIBILITY

Excerpt from Noise Reduction Techniques in Electronic Systems - H.W. Ott; Wiley, 1988:

SUSCEPTIBILITY:
In August, 1982 the US Congress amended the Communications Act of 1934 (House Bill #3239) to give the FCC authority to regulate the susceptibility of home electronics equipment and systems. Examples of home electronic equipment are radio and television sets, home burglar alarm and security systems, automatic garage door openers, electronic organs, record turntables and stereo/high fidelity amplifier systems. Although this legislation is aimed primarily at home equipment and systems, it is not intended to prevent the FCC from adopting standards for devices that are also used outside the home. To date, however, the FCC has not acted on this authority. Although it published an inquiry into the Problem of Radio Frequency Interference to Electronic Equipment (General Docket No 78-369), the FCC relies on self-regulation by industry. Should industry become lax in this respect, the FCC may move to exercise its jurisdiction.

Surveys of the electromagnetic environment (Heirman 1976; Janes 1977) have shown that a field strength greater than 2 V/m occurs about one percent of the time. Since there is no legal susceptibility requirement for commercial equipment, a reasonable immunity level objective would be 2 V/m.

The government of Canada has released an Electromagnetic Compatibility Advisory Bulletin (EMCAB 1) in which it defines three levels or grades of immunity for electronic equipment and states the following:

(a) Products that meet GRADE 1 (1.0 V/m) are likely to experience performance degradation.

(b) Products that meet GRADE 2 (3.0 V/m) are unlikely to experience degradation.

(c) Products that meet GRADE 3 (10 V/m) should experience performance degradation only under very arduous circumstances.

Excerpt from ***EMC - Theory to Practical Design*** - Chatterton/Houlden; Wiley, 1991:
At a distance r (in the far field) from the transmitter, the electric field strength will be:

$$\text{i.e.} \qquad E^2 = \frac{Z_0 \langle P \rangle}{4\pi r^2} V/m$$

$$E \approx \frac{1}{r}\sqrt{30\langle P \rangle}\, V/m$$

Note: For a radiating antenna

$$\langle P \rangle \approx P_t g_a g_t$$

where p_t is the power input to the transmission line feeding the antenna, g_t is the gain in this line and g_a is the antenna gain.

It is useful to realize that a field of order 1.0 V/m can be thought of as a large field, since FCC emission limits for domestic digital equipment are specified in the 100-200 µV/m range) and typical TV and radio receivers can easily detect field strengths of a few mV/m. Also, small amounts of power radiated from a system can give rise to quite large fields in the vicinity. For example, a system radiating a total of only 1.0 mW could generate fields of order 58 mV/m at a (far field) distance of 3.0 m. Enough to affect seriously nearby radios tuned to the same frequency range. On the other hand, fields due to lightning are in the range 1 to 10 kV/m and EMP pulses up to 50 kV/m.

ENGINEERING REPORT ON ELIMINATING ELECTRICAL INSTABILITY AT RADIO TRANSMITTER INSTALLATIONS

1 CAUSES OF INSTABILITY

Electrical instability often occurs at radio transmitter installations due to the radiated signal from the antenna being fed back to sensitive circuits in the transmitter. This can cause both a degradation of signal quality and failure of electronic components within the transmitter.

1.1 Electromagnetic Feedback:

A feedback path can result by electromagnetic induction from the antenna's radiation field to conductors within, or connected directly to, the transmitter. As an example, Figure F-1 shows the field strength in volts per metre for a low powered (25 watt) transmitter feeding a 12 metre antenna at a frequency of 200 kHz at various distances from the antenna's vertical radiating element. As shown, the field strength (volts per metre) increases dramatically as the distance from the antenna is reduced.

1.2 Antenna Current Feedback

A second less obvious feedback mechanism is illustrated in Figure F-2. A feedback path can occur where the AC line supply to the transmitter and the coaxial feeder cable connecting the transmitter to the antenna tuning unit act as one of the antenna's ground radials. The complete set of ground radials collectively provides the return path for the total antenna current to the tuning unit ground terminal. When the ground radials are too short or are broken or when the transmitter is sited too close to the antenna, this can result in a significant proportion of the antenna current flowing in the AC line cables and the screen of the coaxial feeder cable. This path obviously includes the framework of the transmitter cabinet, which can result in undesired feedback to sensitive electronic circuits within the transmitter.

2 METHODS OF AVOIDING FEEDBACK

Three basic techniques which may be used to avoid feedback are described below.

2.1 Maximizing Distance Between Transmitter and Antenna System:

It is generally preferred to locate the transmitter building on the outer edge of the antenna system which includes the antenna structure together with it's circle of ground plane radials. In the case of very high-powered installations the power losses in the feeder cable are a further consideration in this respect. It is often customary to bury the feeder cable below the ground radials.

2.2 Screening The Transmitter Building:

The installation of a set of conductor wires on the surface of the transmitter building as shown in Figure F-3 can often be beneficial in reducing the feedback caused by the antenna's electromagnetic field described in paragraph 1.1 of this report.

2.3 Using Toroidal Ferrite Cores:

The use of toroidal ferrite cores to crate series impedance in the cabling which connects to the transmitter can be very beneficial. The cables of any closed electrical circuit in which the supply and return currents are exactly equal by opposite in direction, may be passed through the centre of a ferrite toroid without producing any net flux in the core. Hence, the toroid is completely transparent in the normal circuit path. A common mode current flowing in either conductor or in both conductors in the same direction will however produce a magnetic flux in the toroid, which thus appears as a series impedance in the circuit.

This effect is illustrated in Figure F-4 for both a pair of open wires such as would be used in ac line supply cabling and for an RF coaxial cable.

2.4 Solution For Antenna Current Feedback Problem:

Figure F-5 illustrates a solution to the antenna current feedback problem described in paragraph 1.2. It is most important to note that all the conductors of the ac line supply cabling, including the metal conduit (when it is used), pass through the same toroid. Individual toroids placed separately on each conductor of the ac line cabling would be saturated by the ac line current and hence would be worthless. It is also important to note that all cables, including grounds or screens must be dealt with, to obtain any improvement.

3. CONCLUSION

Maintaining a suitably large separation between the transmitter and the antenna system is the most reliable method of ensuring overall system stability at radio transmitter installations. System stability can, however, often be achieved where the separation is inadequate by screening the transmitter building and installing ferrite chokes on the transmitter's input and output cabling. It may be noted that both of the techniques described above are consistent with the need to provide protection from equipment damage due to lightning strikes. This subject is covered more fully in Nautel Engineering report 'Lightning Protection For Radio Transmitter Installations".

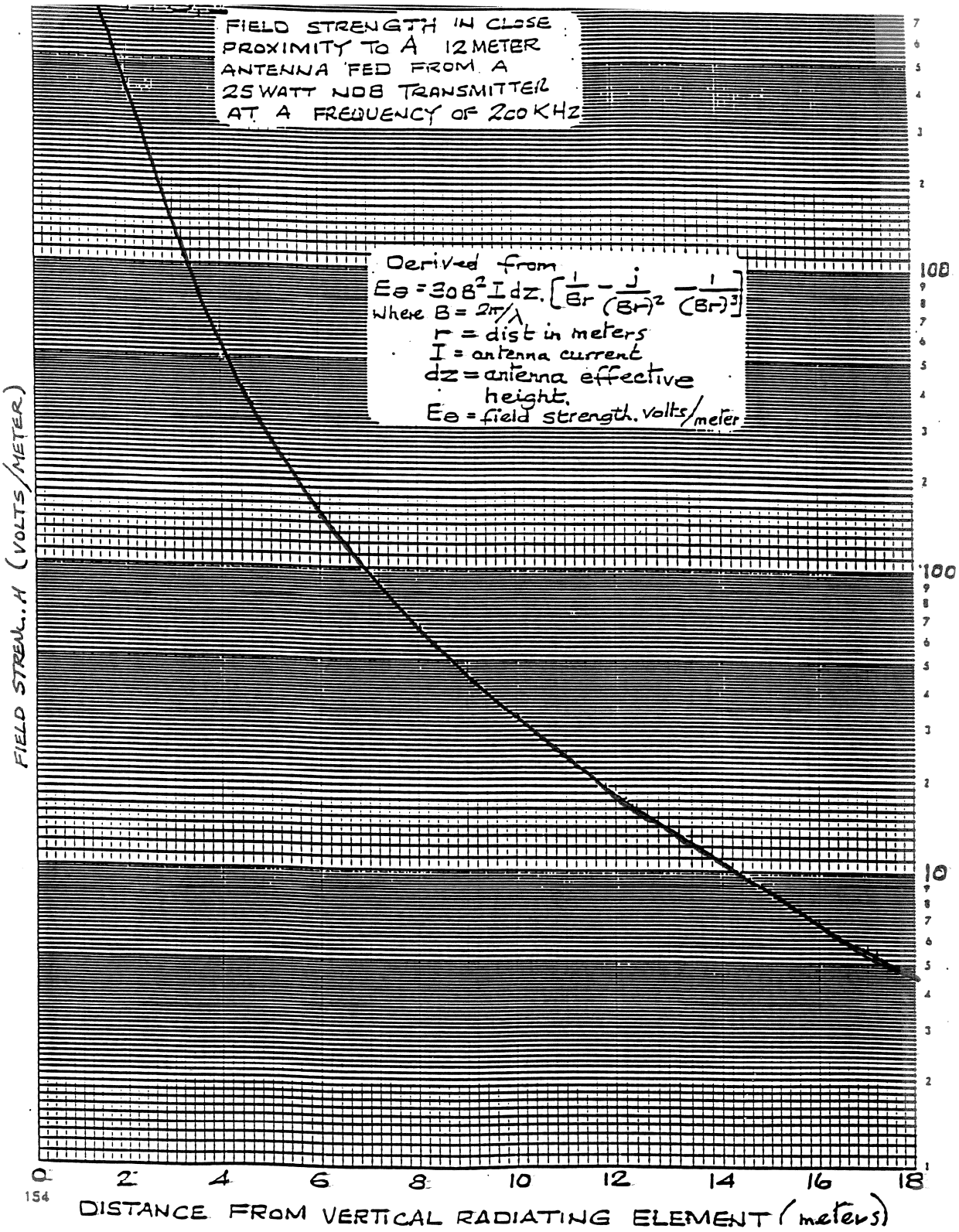


Figure F-1 Electromagnetic Feedback

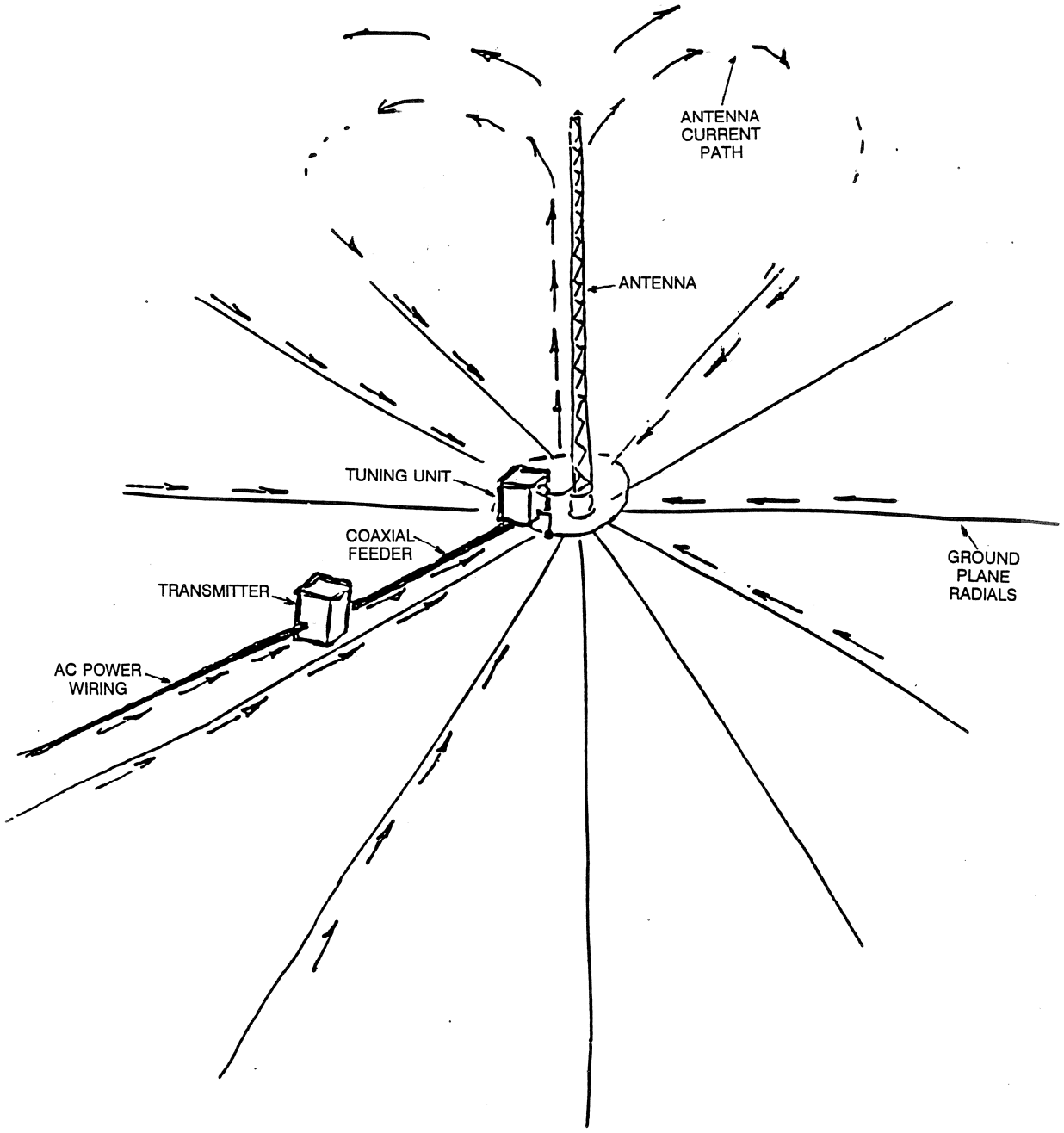


Figure F-2 Antenna Current Feedback

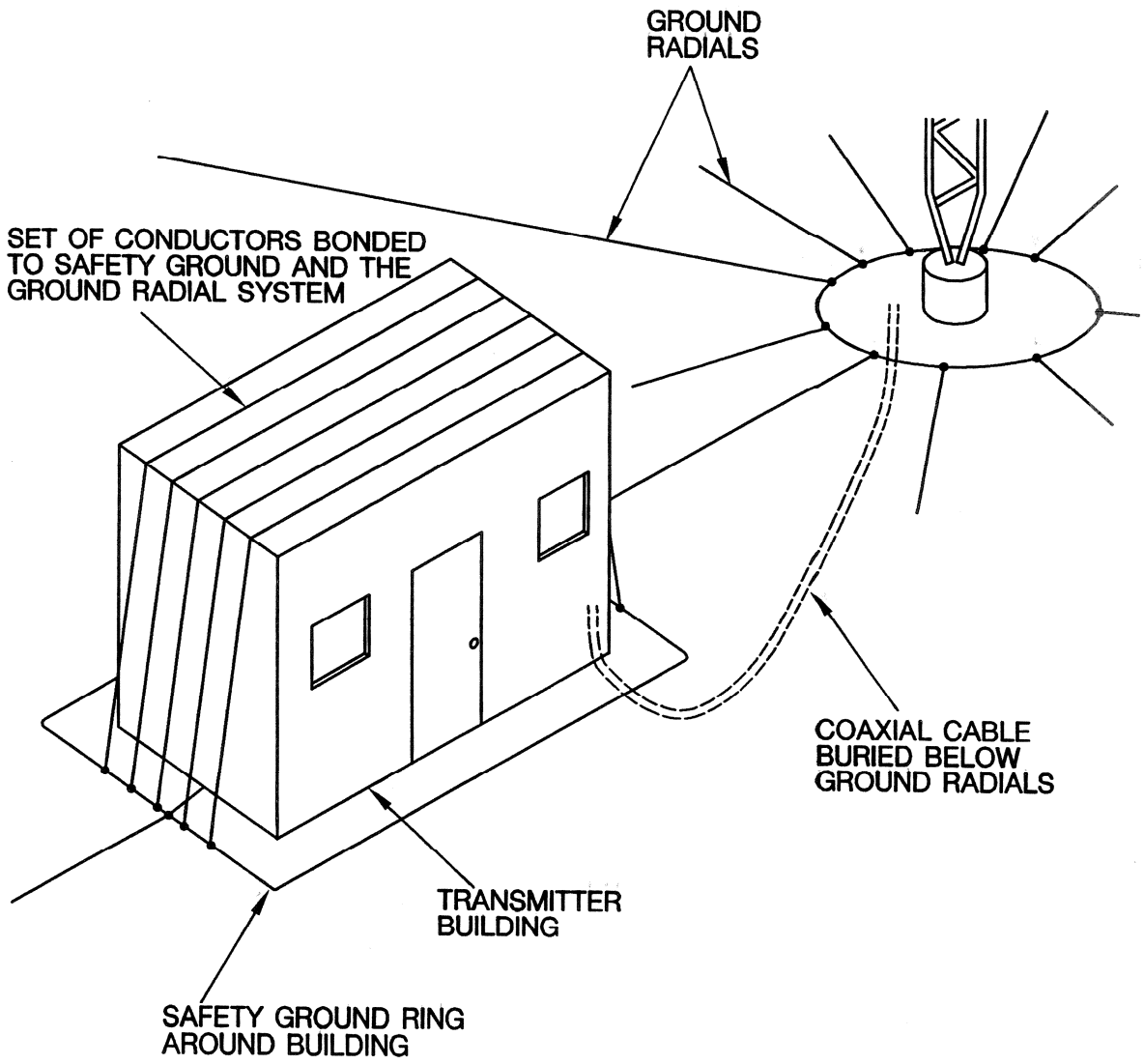


Figure F-3 Screening of Transmitter Building

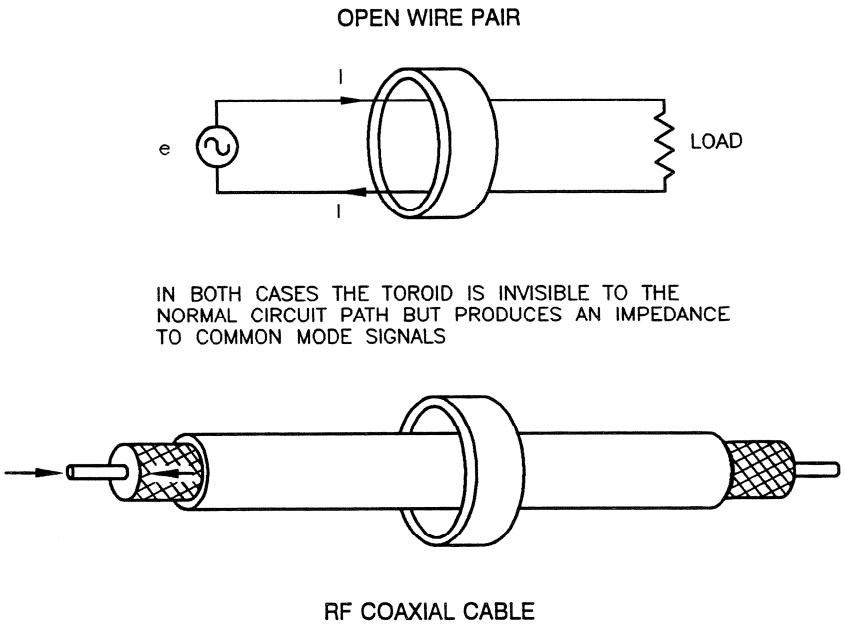


Figure F-4 Use of Toroids to Impede Common Mode Signals

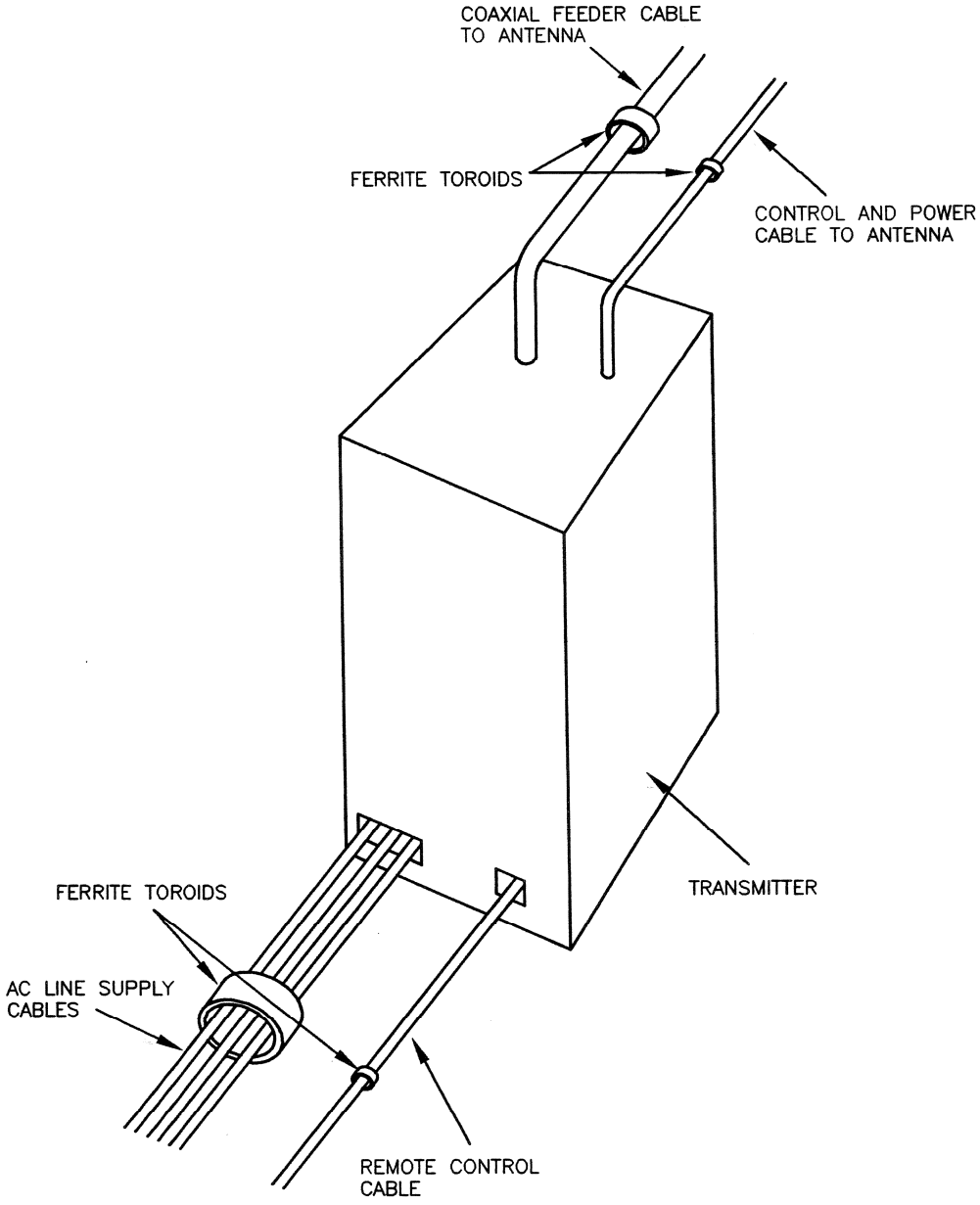


Figure F-5 Antenna Current Feedback Solution Using Toroids

APPENDIX G
NAUTEL'S LIGHTNING PROTECTION SUPPLEMENT

1 OVERVIEW

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 which 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).

2 LIGHTNING CHARACTERISTICS AND INCIDENCE

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 than 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% 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

Convention 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. The current peak value will obviously vary widely from strike to strike and Figure 3 shows an empirical probability distribution for this value. It may be seen to have a median value of about 20,000 amperes. The pulse length (to half amplitude) also has a probability distribution ranging from 20 to 100 microseconds with a median value of 40 microseconds.

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 5 microseconds to peak amplitude.

3 PROTECTION PRINCIPLES

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 to 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 which 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 principle for a typical transmitter site. As show, 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.

4 RECOMMENDED INSTALLATION CONFIGURATION

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 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 by 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 surge 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 which 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 which 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 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 center 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 transmitter's 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 suggest, 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 of 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 sever weather conditions. The balls should be alighted 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 1 MHz is approximately 9.4 kV 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 x Za x 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 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 to 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.

5 TRANSMITTER BUILDING LAYOUT

The geometry of the interconnections in an 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. The 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 illustrate in Figure 6:

(a) The ac power cable is fed from the left hand side of the building while the coaxial feed and other antenna connections are fed from a diametrically opposite point at the right hand side.

(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 hand side of the diagram, most of the lightning current would still tend to flow in the direct path through the transmitter due to its relatively low impedance compared to the alternative longer path through 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. Carefully consider the following factors 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 grounded 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 lightning 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.

6 AC LINE SURGE PROTECTORS

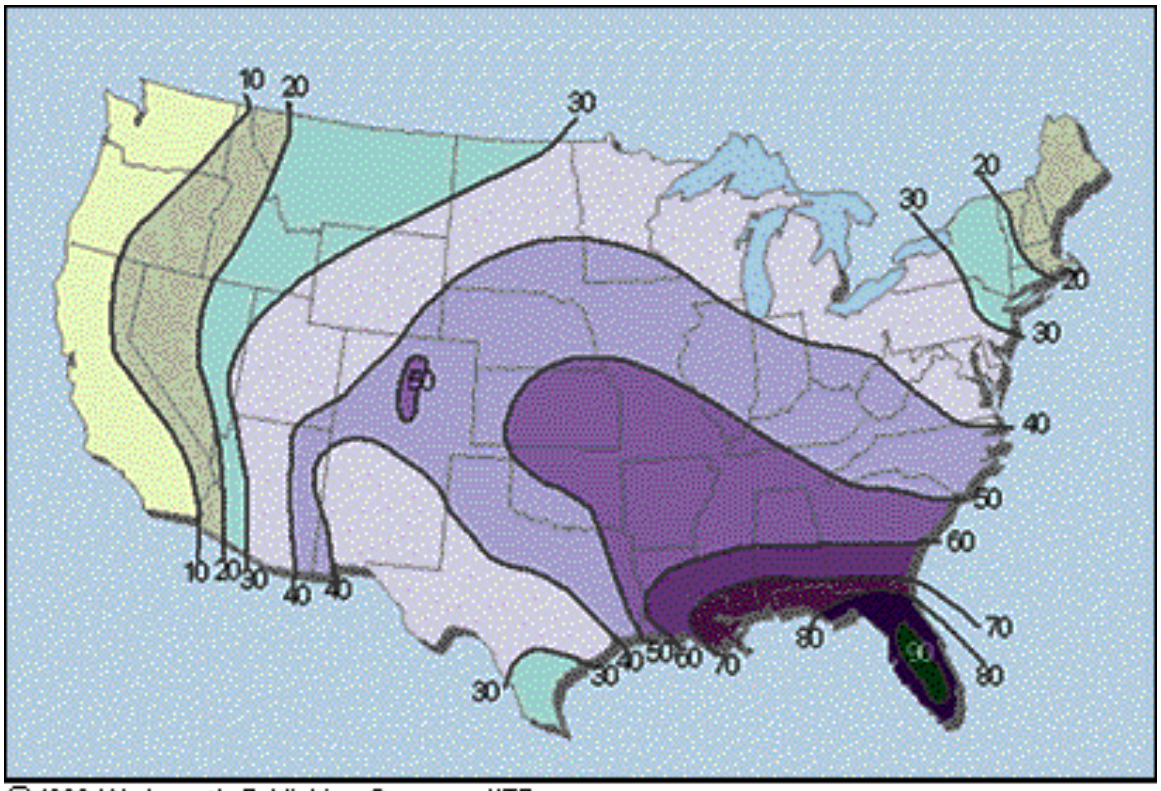
The ac line supply to the transmitter building usually represents the lowest impedance to remote grounds and will therefore carry most of the lightning current flowing away from the transmitter site. The surge protectors which connect between the station reference ground and the ac line cables must be 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 which 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.

7 IMPLEMENTING PRACTICAL SOLUTIONS

'An ounce of prevention is worth a pound of cure' is a well known adage which is highly 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.



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Figure 1 Mean Annual Number of Days with Thunderstorms in the United States

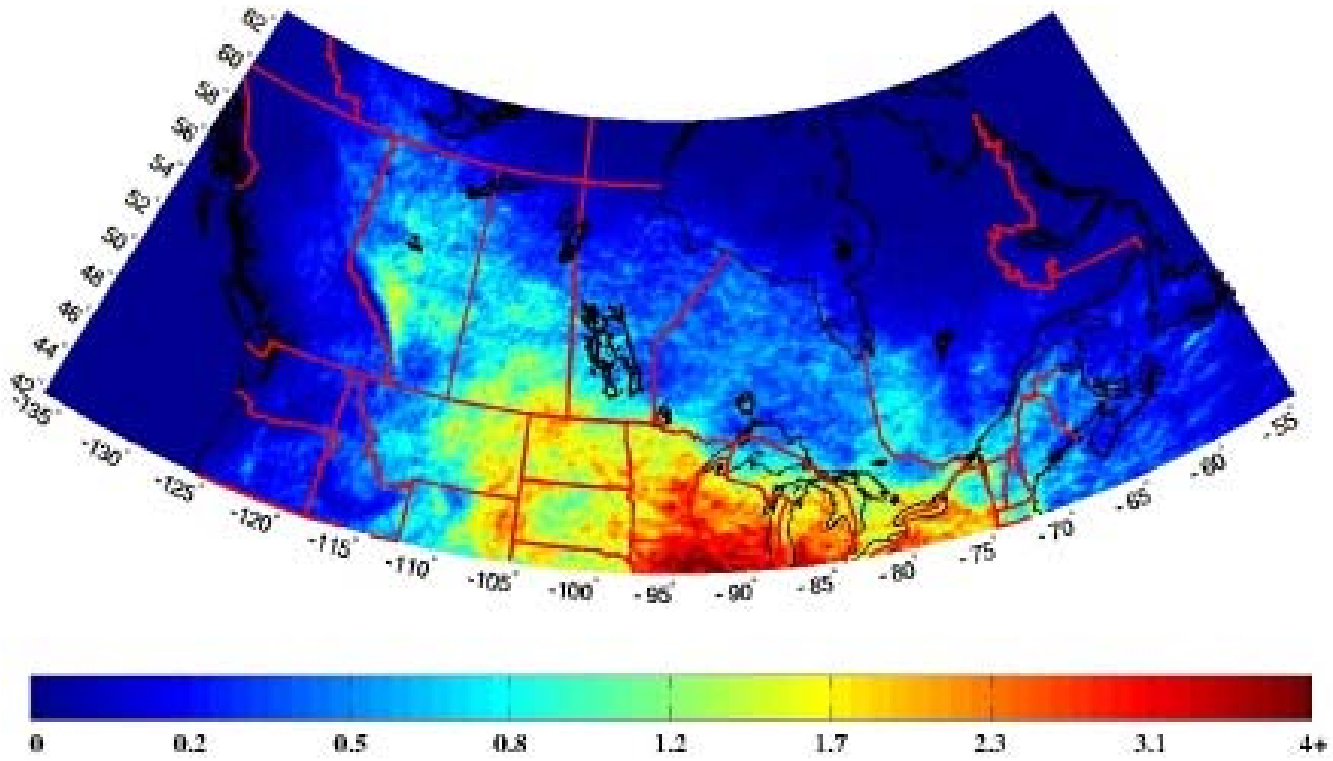


Figure 2 Annual Average Number of Days with Thunderstorms in Canada

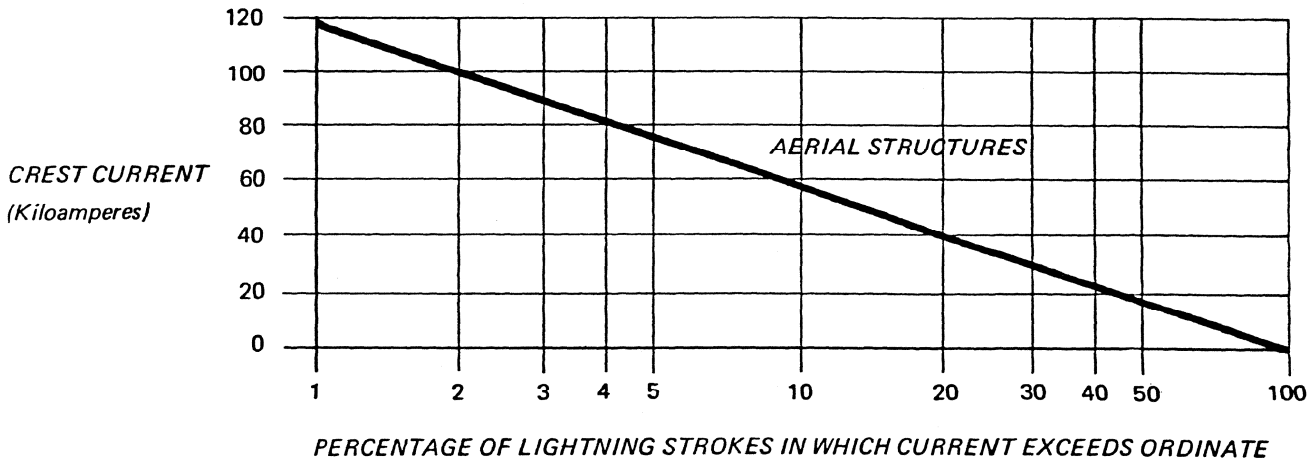


Figure 3 Magnitude Distribution of Currents in Lightning Strokes To Structures

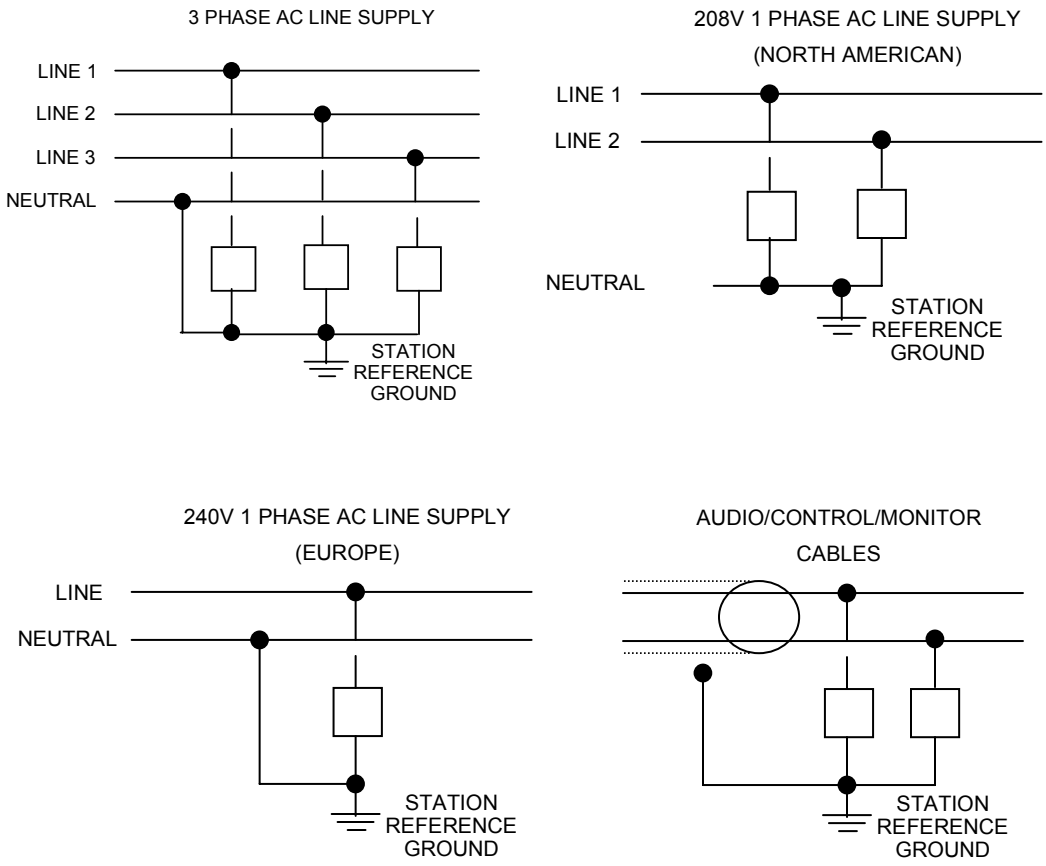


Figure 4 Surge Protector Connection On Power, Audio, Control and Monitor Wires

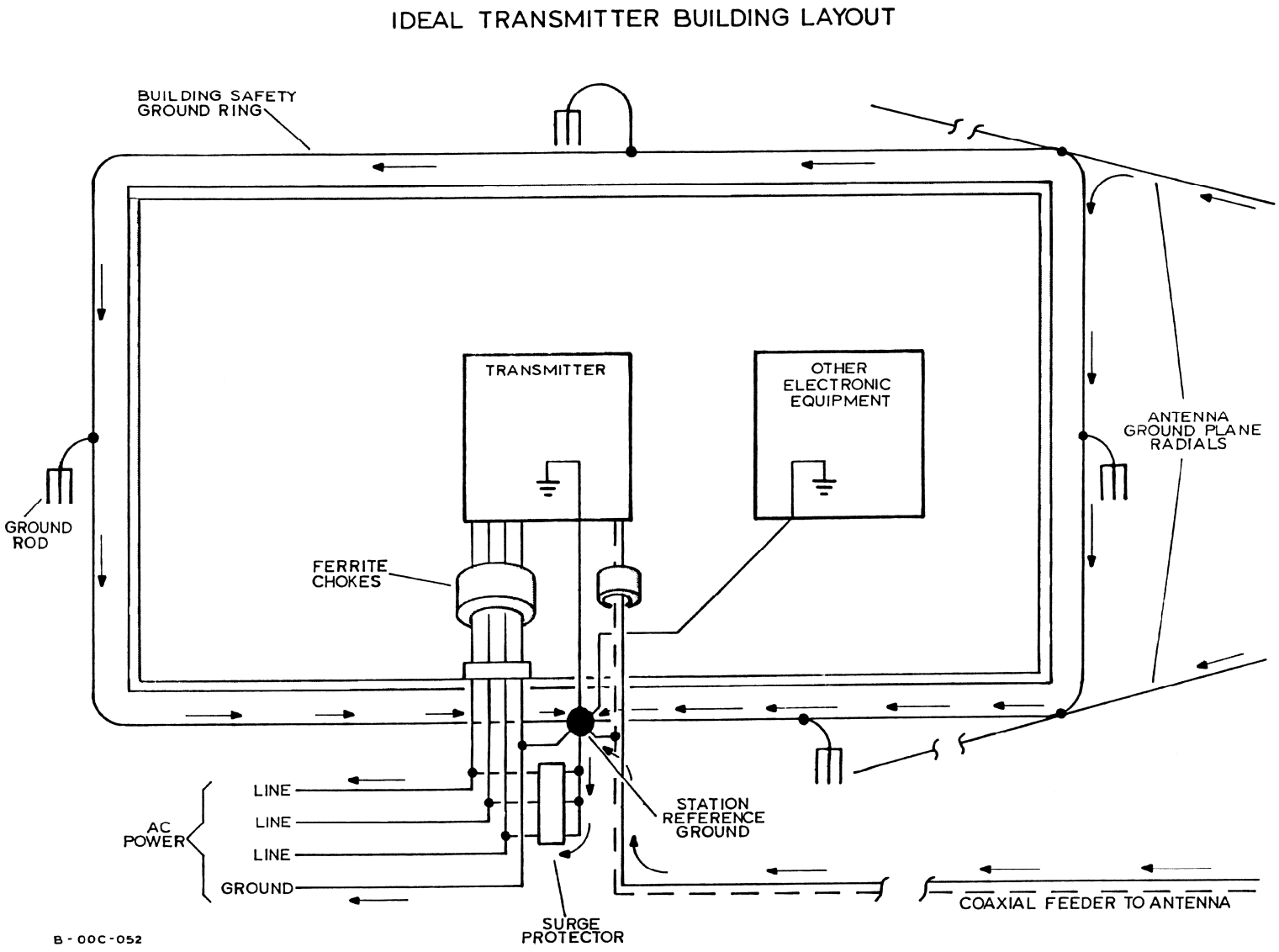


Figure 5 Ideal Transmitter Building Layout

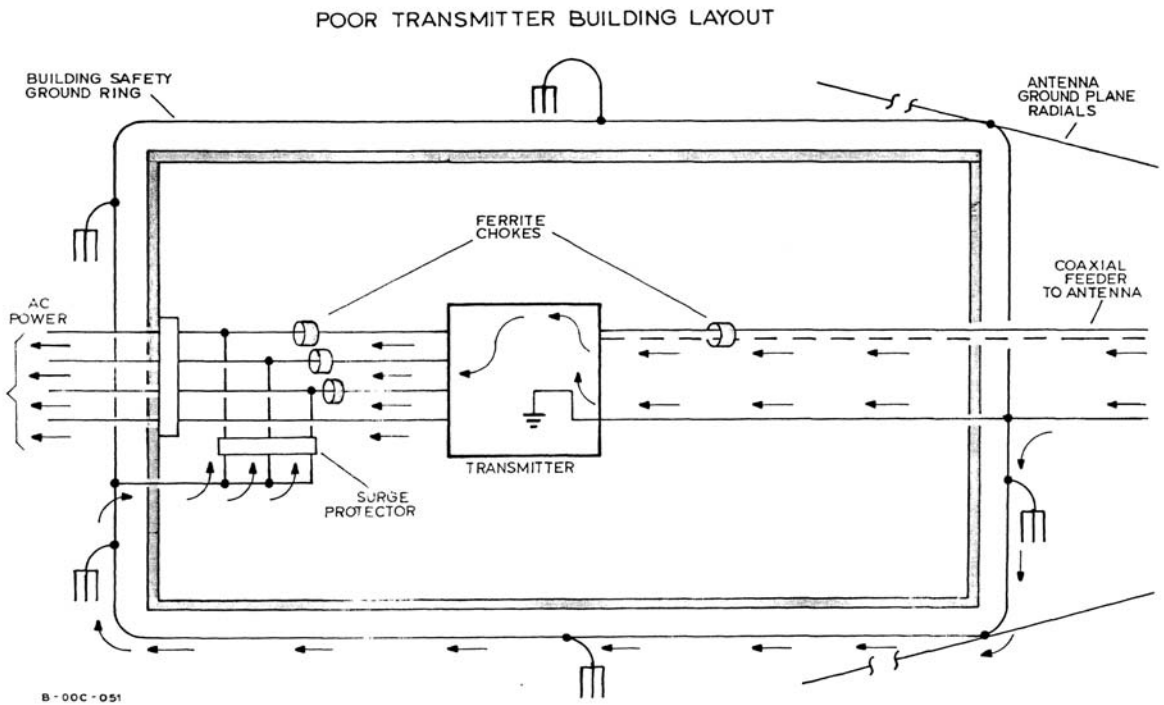


Figure 6 Poor Transmitter Building Layout

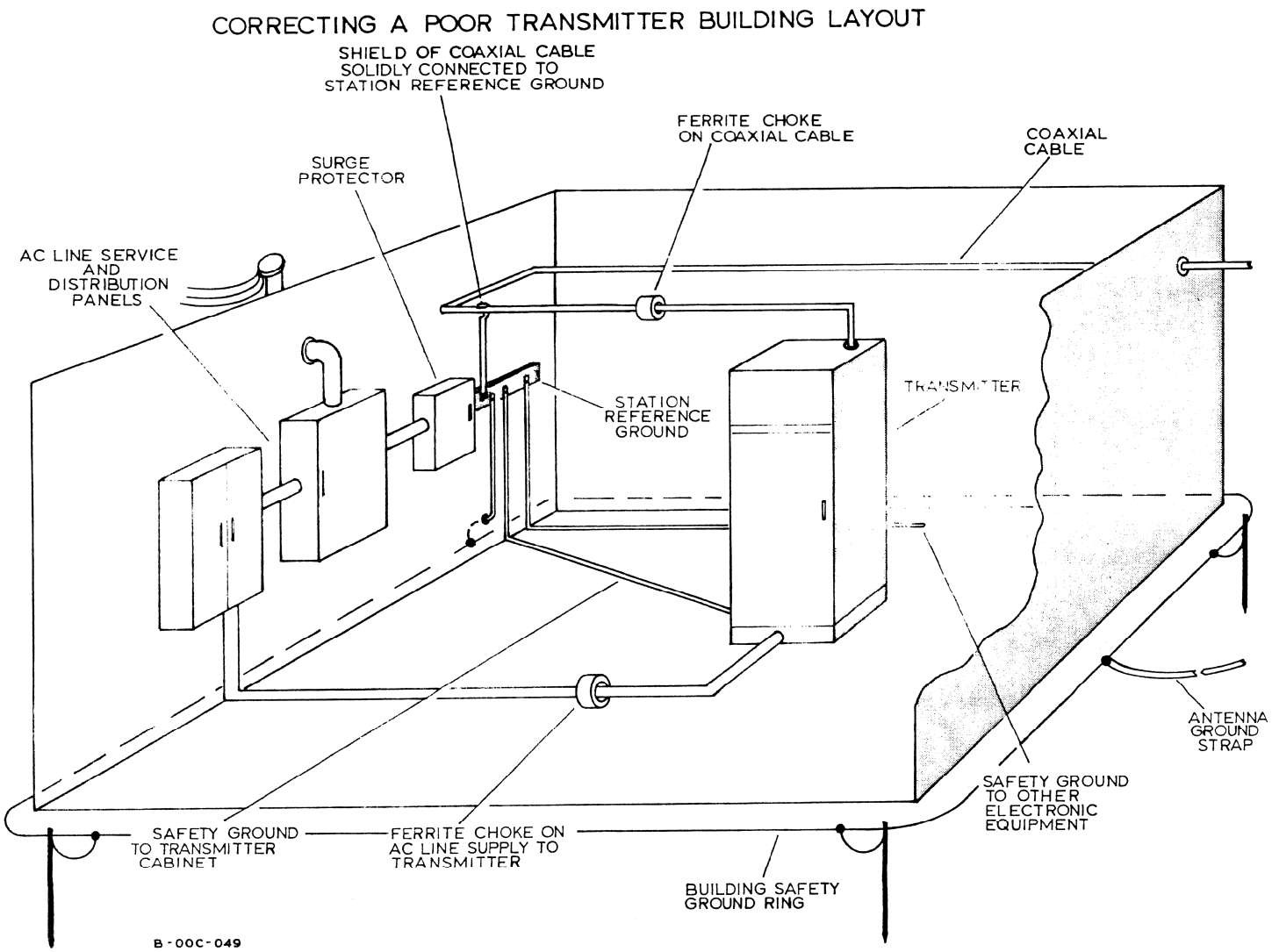
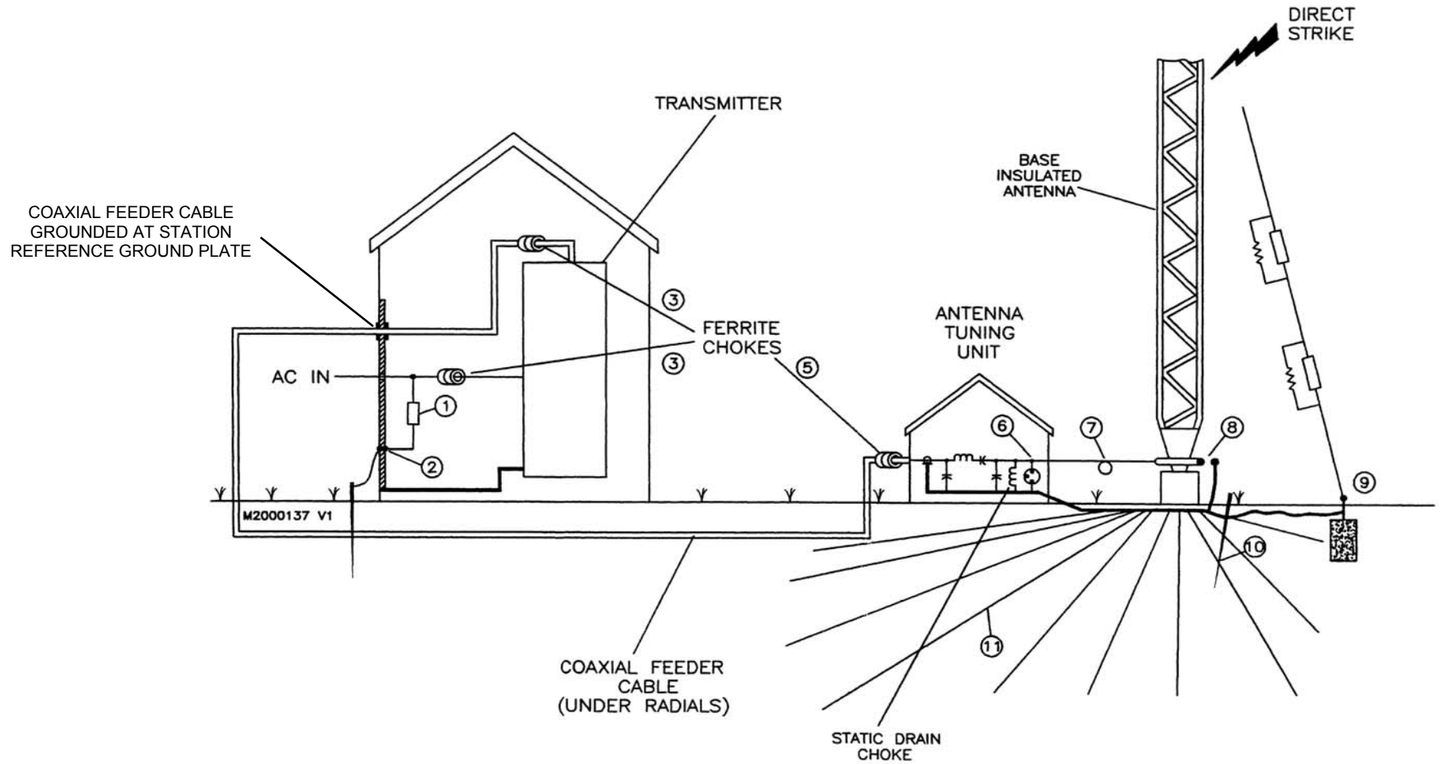


Figure 7 Correcting A Poor Transmitter Building Layout



Dimensions = mm (inches)

Recommended Installation Configuration			
Issue 3.1	Not to Scale	Figure 8	Sheet 1 of 1

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.