Guide to Lightning Protection of Series 7000 DF Antennas

A Technical Application Note from Doppler Systems

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1.0 Introduction

Prior to the introduction of the series 7000 DF systems, our antennas were all aluminum with the structure supported by a conductive aluminum mast that was, in turn, mounted by the user to his tower or other mast. This provided a grounded support. Some of our customers used lightning rods or "puff ball" type static dissipaters which were mounted to the top of our antennas using an extension mast (also aluminum).

To achieve the improved accuracy in the series 7000 antennas, we no longer use a conductive mast. Instead it is fiberglass so as to prevent any disturbance to the RF field around the antenna elements. Both the control cable and the coax cable which connect to the antenna are isolated through the use of ferrite suppressors so as to make these cables appear transparent at RF as well. The antenna frame is still grounded through the shielding on these cables, but this of course is not designed to carry high currents.

To provide lightning protection for the DDF709X series of antennas, multiple appropriately positioned lightning rods should be used. This application note discusses the placement of the lightning rods so as to provide adequate protection while not degrading the DF performance.

2.0 The Rolling Sphere Method for Positioning Lightning Rods (Air Terminals)

An excellent reference for designing a lightning protection system is contained in the reference, ***ERITECH LIGHTNING PROTECTION HANDBOOK*** [1]. Some of the explanation below is taken from this reference. In the US, the ***NFPA 780 STANDARD FOR THE INSTALLATION OF LIGHTNING PROTECTION SYSTEMS*** [2] should also be consulted. Another highly readable presentation is ***LIGHTNING PROTECTION SYSTEM (PALACE OF FESTIVALS OF CANTABRIA, SPAIN)*** [3] by Marta García Castillo.

During a lightning discharge, air immediately below the storm cloud is ionized forming a discharge channel extending 10 to 200 meters. This is the initial streamer, and it is shortly followed by a second and subsequent streamers which move erratically towards the ground. When the stepped leader gets within 20 to 60 meters of the earth, an upward leader forms to meet the downward leader and high current discharge occurs.

The idea behind air terminal placement is to provide low impedance paths capable of withstanding the high current of a lightning strike in such positions that other more sensitive objects are protected. The greater the charge of the downward leader, the greater the striking distance will be, and the larger the resulting current. A single lightning rod will protect a larger area against stronger strikes rather than against weaker ones, so if a structure is to be protected for nearly all lightning strikes, including weaker ones, more lightning rods spaced closer together are required.

The International Electrotechnical Commission or IEC has established four levels of protection corresponding to the degree of protection afforded. For each of these levels, two peak currents are defined. The maximum peak current is used for sizing the conductors in each lightning rod. The minimum peak current is used to determine the spacing between lightning rods. Both peak currents have a statistical probability associated with them since there is no 100% effective solution.

Table 1 – Maximum currents for sizing the lightning protection devices for various levels of protection (from ref 1)

Lightning Parameter	Lightning Protection Level I	Lightning Protection Level II	Lightning Protection Level III	Lightning Protection Level IV
Max Peak Current	200 kA	150 kA	100 kA	100 kA
Probability that the peak current is greater than Max	1%	2%	3%	3%

Table 2 - Minimum currents for calculating the lightning protection geometry for various levels of protection (from ref 1)

Lightning Parameter	Lightning Protection Level I	Lightning Protection Level II	Lightning Protection Level III	Lightning Protection Level IV
Min Peak Current	3 kA	5 kA	10 kA	16 kA
Probability that the peak current is greater than the Min	99%	97%	91%	84%
Striking Distance	20 m	30	45 m	60 m

So, for example, if we want to provide protection level III, the lightning rod and ground conductor should be sized to carry 100 kA if it is to survive 97% of the strikes, and the spacing between lightning rods should be adjusted so as to attract 91% of all strikes having a potential that will produce a current of 10 kA or more. This potential corresponds to a striking distance of 45 meters.

Since the location of the downward leader can be anywhere relative to the air terminals, a hypothetical rolling sphere having a radius equal to the striking distance is used to determine the region of protection for an array of lightning rods. The center of the sphere corresponds to the end of the downward stroke leader.

As an example of how this method works for designing a lightning protection system for a complex building structure, see Figure 1 below.

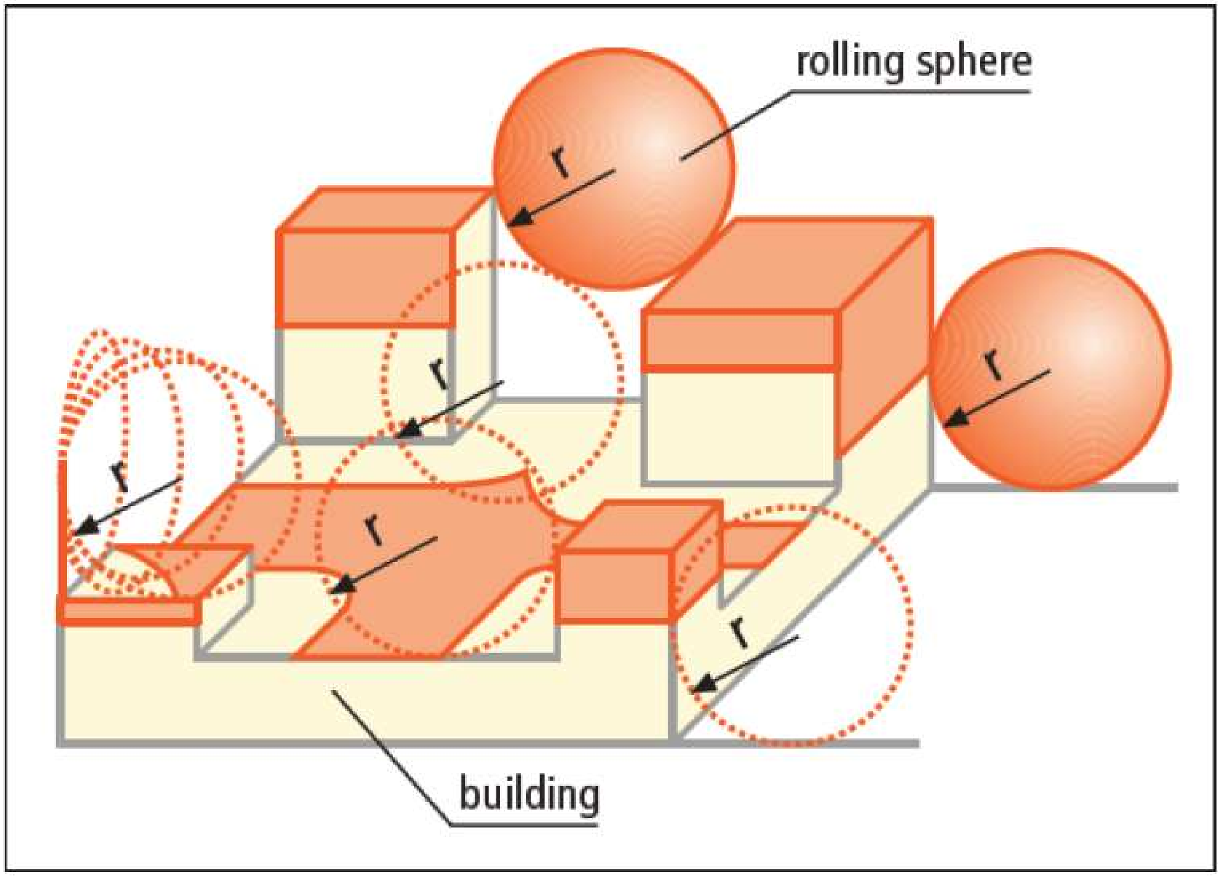

Figure 1 - Example of use of rolling sphere to identify points requiring lightning protection (from ref. 3)

A sphere having a radius equal to the striking distance is rolled around the entire unprotected structure and all points of contact are noted (in orange). These are all potential points of lightning strike. Air terminals are then added and the process is repeated (rolling it over the air terminals) to assure that all locations needing protection are not contacted by the surface of the rolling sphere.

3.0 Lightning Protection of DF Antenna

If the DF antenna is placed on a roof top or on open level ground, it requires a system of lightning rods that are taller than the highest point of the DF antenna. How much taller depends on the radial distance between the antenna and the array of rods. Using the rolling sphere model, we can calculate this vertical height. With three or more rods positioned in a circle with the DF antenna in the center, the radius of this circle and the radius of the sphere determine the penetration depth (the vertical distance penetrated by the sphere).

In Figure 2, the VHF antenna is shown with the 45 meter (150 ft.) rolling sphere sitting on top of four lightning rods positioned in a square having a side of 20*sqrt(2) ft. The view is along the diagonal of the square array. Note that the penetration depth is about 16 inches.

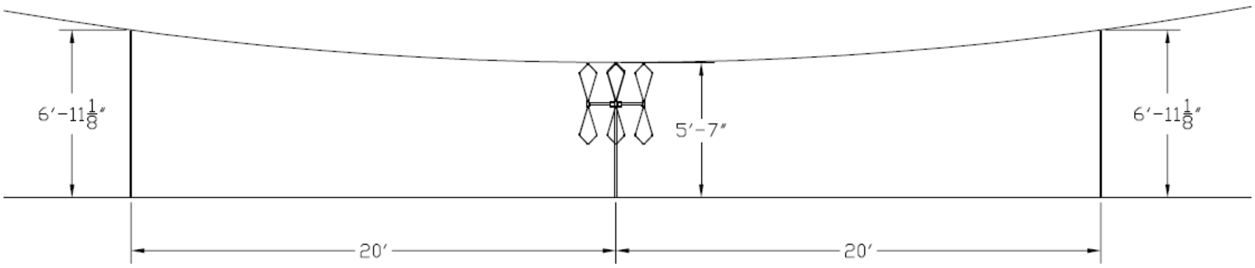

Figure 2 - 150 ft. sphere above DF antenna

The calculation of this height is straight forward and is shown below as a function of the radial distance. Again, a 150 ft. sphere is assumed (LPL III).

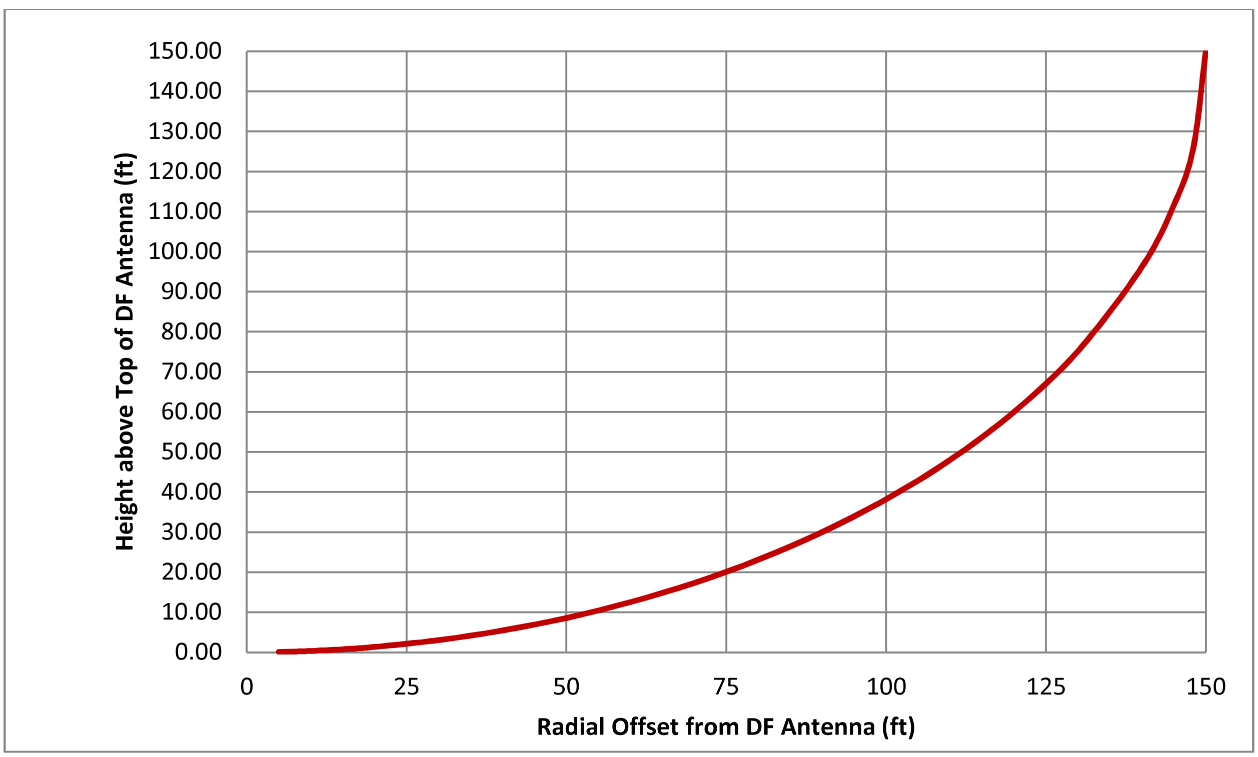

Figure 3 - Minimum height of lightning rods above top of DF antenna

4.0 Effect of Lightning Rods on DF Performance

Conducting objects such as lightning rods placed in the vicinity of the DF antenna array alter the radiation pattern of the array, and can potentially degrade DF system performance. A systematic approach to quantitatively evaluating the impact of lightning rods on DF performance involves obtaining the radiation patterns of the DF antenna array with the nearby lightning rods, and then using these radiation patterns in a system simulation to determine the bearing error as a function of angle of incidence.

As a typical scenario, we assumed an eight dipole element DF array mounted 100 feet above a perfectly conducting ground plane. (This would correspond to the roof of an 8 story building). Three or four lightning rods were positioned symmetrically on a circle with the DF array in the center. The lightning rods extended from the ground to a certain height above the DF array that depends on the radius of the circle in accordance with the rolling sphere model.

Figure 4 shows the RMS bearing error over all incidence angles for the cases of three and four lightning rods as a function of their radial offset from the center of the DF array. As can be seen the RMS bearing error tends to decrease as the lightning rods are moved farther from the DF array. However, the behavior not monotonic; there is some oscillation in the values as the radial offset increases. The green solid line plotted in the figure shows the efficacy of a simple formula to estimate the RMS bearing error as a function of radial offset. This simple formula is useful for back-of-the-envelope estimates in lieu of detailed electromagnetic and system simulations.

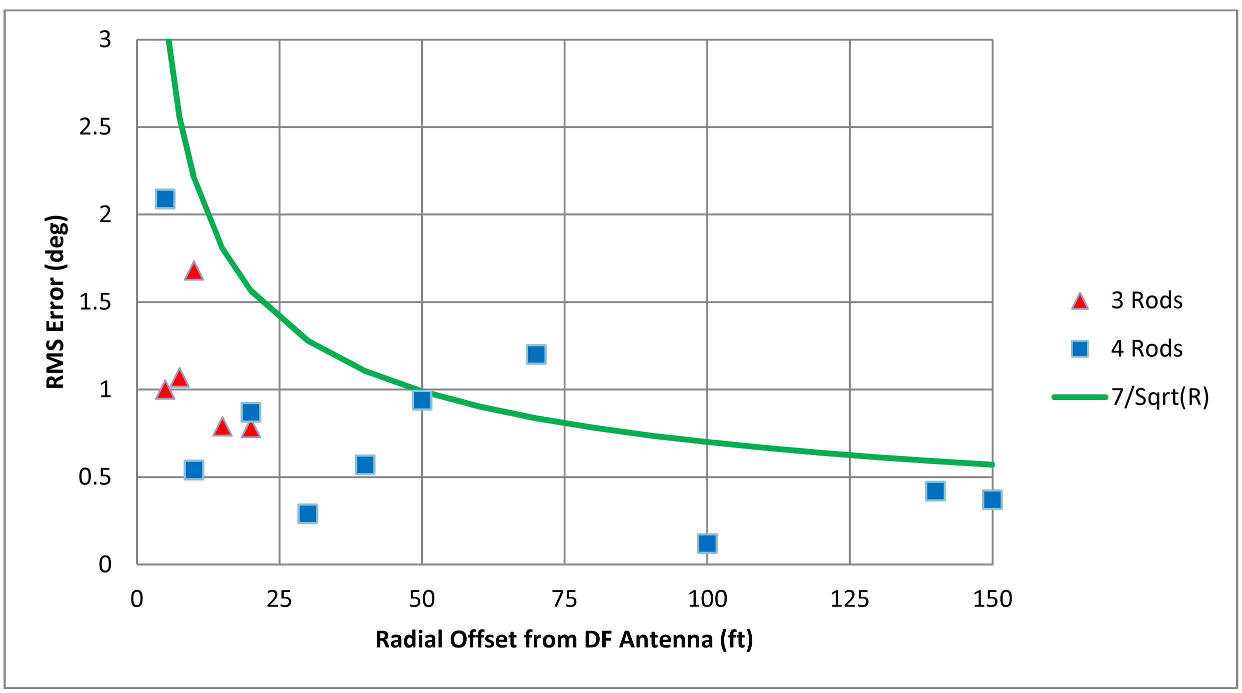

Figure 4. RMS bearing error over all incidence angles for three and four lightning rods as a function of the radial offset from the center of the DF array.

Based on Figures 3 and 4, we would recommend that the lightning rods be located at a radial distance of 50 ft. with the rods 10 ft. higher than the DF antenna or at a radial distance of 75 ft. with the rods 20 ft. above the top of the DF antenna.

5.0 References

1. ***ERITECH LIGHTNING PROTECTION HANDBOOK***

2. ***NFPA 780 STANDARD FOR THE INSTALLATION OF LIGHTNING PROTECTION SYSTEMS***

3. ***LIGHTNING PROTECTION SYSTEM (PALACE OF FESTIVALS OF CANTABRIA, SPAIN)*** by Marta García Castillo