GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO . 10, PAGES 1487-1490, MAY 15, 2000

Measurements of Lightning Rod Responses to Nearby Strikes

C.B. Moore, G.D. Aulich, and W. Rison
Langmuir Laboratory for Atmospheric Research, New Mexico Institute of Mining and Technology, Socorro, New Mexico

Received September 7, 1999, revised December 10, 1999, accepted January 5, 2000

Abstract:

Following Benjamin Franklin's invention of the lightning rod, based on his discovery that electrified objects could be discharged by approaching them with a metal needle in hand, conventional lightning rods in the U.S. have had sharp tips. In recent years, the role of the sharp tip in causing a lightning rod to act as a strike receptor has been questioned leading to experiments in which pairs of various sharp-tipped and blunt rods have been exposed beneath thunderclouds to determine the better strike receptor. After seven years of tests, none of the sharp Franklin rods or of the so-called "early streamer emitters" has been struck, but 12 blunt rods with tip diameters ranging from 12.7 mm to 25.4 mm have taken strikes. Our field experiments and our analyses indicate that the strike-reception probabilities of Franklin's rods are greatly increased when their tips are made moderately blunt.

Paper number 1999GL011053.

Introduction

At the present time there is no generally accepted standard for the tip configuration of a lightning rod, but, following Benjamin Franklin's writings [*Franklin*, 1753], sharply-tipped rods have been used for many years. Franklin invented the sharp lightning rod after he found that he could discharge electrified objects silently, without a spark, by approaching them with a metal needle in his hand. This led him to speculate that perhaps lightning could be prevented by erecting a sharp iron rod which would discharge thunderclouds overhead. However, instead of eliminating the electricity in the thunderclouds that passed over, some of his rods were struck by lightning which led him to suggest that they provided preferential paths to Earth for lightning that had not been neutralized. Despite this new and unexpected function that his rods appeared to serve, *Franklin* [1767] remained enamored of the "power of a point" and recommended that the tips of lightning rods be sharp, a configuration that is still widely used today although the virtue of having sharp tips on lightning rods has never been established. Our assessment of the experience gained since Franklin's time is that sharp rods exposed in isolation on church steeples and other high towers are often struck by lightning whereas similarly sharp Franklin rods installed with lesser isolation are sometimes not struck, other objects in the vicinity being the strike receptors.

Phelps [1971] has shown that strong electric fields are necessary for the propagation of lightning plasma streamers and leaders through the air. It has also long been known [*Kip*, 1938] that the local electric fields are concentrated around the tip of a sharp metal rod causing the formation of ions in the surrounding air which move so as to weaken the electric fields. This gives rise to a puzzle: How do sharp rods over which field-weakening ions readily form serve as lightning receptors for which strong fields are required?

To complicate the matter further, in recent years several new devices have been offered for lightning protection with the claims that they emit upward-going, return stroke streamers earlier than possible from Franklin rods. Many of these devices employ sharp-tipped electrodes; others augment the sharp tips with radioactivity [*Berio*, 1970]. It has been asserted that these so-called "early-streamer-emitters" ("ESE" devices) have much greater "zones of protection" (with radii of up to 100 m) than those of Franklin rods and therefore that a single "ESE" device can provide better and less-expensive protection than can a large array of Franklin rods.

A Competition for Lightning Strike Reception

In an effort to compare the strike reception effectiveness of lightning rods with various tip configurations, we carried out an experiment around the 3288-m high summit of South Baldy Peak in the Magdalena Mountains of central New Mexico. Test rods were mounted in insulators on top of 6-m high pipe masts and connected to Earth by #10-wire "down conductors" that passed through nominal 2-A fuses. Adjacent to each sharp-tipped rod, at a distance of about 6 m, we mounted a similarly exposed, blunt, round metal rod (usually made of aluminum), the top of which had been turned into a smoothly-polished hemisphere. (Our calculations indicate that the perturbation in the field strengths at one of the tips produced by an adjacent, competing rod was about 1% of the ambient field strength, and therefore, the rods did not significantly interfere with each other.) The diameters of the blunt rods used in these tests ranged from 9.5 mm to 51 mm.

This competition between sharp and blunt tipped rods for receiving lightning strikes has been carried out during the past seven summer thunderstorm seasons with the results that none of the sharp-tipped rods have taken a strike whereas 12 of the adjacent blunt rods participated in discharges and acquired weld-marks on their tips. A photograph of six blunt rods that have been struck is shown in Figure 1. None of the exposed 9.5-mm or the 51-mm diameter rods was hit; most of the strikes have been to 19-mm diameter rods. Two different, sharp-tipped "ESE" devices were included in these tests but neither of them has been struck although other objects within their 100-m claimed zones of protection took strikes. Twelve strikes were near a radioactive "ESE" device and two strikes were also adjacent to a sharp, high-tech, French "air terminal" (which was tested for only a three year period).

An Analysis of the Electric Fields around Lightning Rod Tips

A calculation of the strengths of the electric fields around the tips of semi-prolate ellipsoids simulating the lightning rod shapes that we used indicates that, while the fields at the tips of a sharp rod are greatly intensified at the tip of a sharp rod, this intensification decreases rapidly with distance from the tip [*Moore et al.*, 1999]. At distances from the tip greater than about one centimeter, the strength of the electric field around the tip of a 10-mm radius tip is found to be greater than that over a simulated, sharp Franklin rod. Close to the tip of a sharp rod, the great enhancement of the electric field is counteracted by the easy formation of ions in that region. Not until after the electric fields acting on these ions have become strong enough to create electron avalanches farther from the tip can a positive leader propagate upward, away from the tip. As an initial negative stepped leader descends from a thundercloud and intensifies the electric fields around exposed conductors below, the strong fields necessary for upward propagation of positive return stroke leaders appear to occur earlier around a moderately blunt tip than around sharp ones. To test this proposed explanation for the favored reception of lightning by blunt rods, we have made some high resolution measurements of the responses of lightning rods to nearby discharges.

Digitized Measurements of Lightning Rod Responses

Three rods were mounted as above in insulators on top of 6-m high, aluminum pipe masts above "Iron Kiva II" , a buried steel room on top of South Baldy Peak. The currents that flowed from these rods during nearby strikes were measured by connecting each rod to a computer-operated digitizer; the connection was made by leading the #10 wire down the center of each pipe mast in a coaxial fashion to the appropriate terminating resistor (157 ohm) at the bottom which was protected from over-voltage by a spark gap. A protective voltage-dividing resistor network connected the signal across the termination to an LF-356 voltage-follower operational amplifier (schematic of the circuit is available at http://www.lightning.nmt.edu/moore/grl_rods.html). Two 12 bit computer-operated digitizers, each having two 5 MHz digitizing channels, were employed within Kiva II. These allowed us to record the simultaneous responses of the three different lightning rods and the change in the strength of the local electric field, sensed as the displacement charge on a nearby electrode that was shielded from rain. The digitizer recordings were initiated by a "trigger" signal generated by the electric field change sensor which was located about 13 m from the center of Kiva II.

Strike to an instrumented blunt rod on June 17, 1999.

No direct strike to any of the instrumented rods occurred until this year when, on June 17, a 19-mm diameter aluminum rod above Kiva II was struck by a four stroke natural lightning discharge. The responses of the three instrumented lightning rods to the first stroke are given in Figure 2 in which it can be seen that, as the descending leader made a step downward, bursts of point discharge current were emitted from each of the three instrumented rods mounted above Kiva II. At about 150 microseconds before the electric field sensor triggered the digitizers, the 19-mm blunt rod emitted a burst of current that persisted and apparently grew into an upwardly-propagating leader with currents in excess of 8 A. A fuse that we had placed in the down-conductor lead (to protect the digitizer) exploded at this time and terminated the blunt-rod current measurement. It is of interest that, during the 70-microsecond burst of current from the blunt rod, the emissions from the two other rods declined, then ceased entirely. The integrated currents during this burst indicate that a positive charge of more than 199 microcoulomb was emitted by the blunt rod, 47 microcoulomb by the "ESE" device and 27 microcoulomb by the Franklin rod.

On lowering the mast supporting the 19-mm-diameter rod,, we saw four weld marks around the rod tip. A discharge had occurred inside the pipe mast near its top, presumably after the fuse in the down conductor failed early in the first strike. All of these indicated that the blunt rod had been struck repeatedly by lightning. On the other hand, there was no evidence of strikes to the tip of either the Franklin rod or to the "ESE" device; in addition, the fuses in their down conductors were intact.

Nearby strike on July 5, 1999.

A widespread thunderstorm produced more than 50 lightning discharges, one of which struck a 12.7-mm diameter rod that was 6 m from a competing, sharp Franklin rod located 42 m west-northwest of the Kiva II center. The responses of the instrumented rods mounted above Kiva II are shown in Figure 3. Note that the red line plotting the small current from the "ESE" device is somewhat obscured by the other traces. Negligible amounts of charge (less than 5 microcoulomb each) were emitted from the Franklin rod above Kiva II and from the "ESE" device but the nearby 19-mm-diameter blunt rod emitted more than 452 microcoulomb of positive charge during the final 150 microseconds of the negative leader's descent. Despite the large emissions of positive charges from the Kiva-mounted blunt rod, its upwardly-going leader did not connect to the stepped leader; the successful positive return stroke was provided by the 12.7-mm-diameter blunt rod located 39 m to the west-northwest.

Rocket-initiated lightning on August 7, 1999.

A lightning discharge aloft was initiated when a small rocket, towing an 86-m length of 0.2-mm diameter steel wire, was launched into a thunderstorm over South Baldy Peak. An observer reported that an upward-going discharge developed above the top of the wire and a discharge went to Earth from the bottom of the wire when it was at a height approximately equal to the length of the wire. A later survey of the area indicated that the lower discharge struck a small pine tree, located about 33-m north-northeast of the center of Kiva II, and browned the tips of the needles on its west side.

Records of the currents emitted by the three instrumented rods installed above Kiva II are shown in Figure 4. The greatest current (about 3.7 A) was emitted by the Franklin rod which was the closest rod to the rocket launcher (about 10 m distant) and to the damaged pine tree (about 30 m distant). While there was no indication that the Franklin rod actually connected with the rocket-initiated negative leader, the integrated current from the Franklin rod during the last 100 microseconds before the strike to the tree amounted to 159 microcoulomb while those from the 19-mm blunt rod and the "ESE" device were both about 13 microcoulomb.

The interesting oscillation in the electric field change record was not a sensor artifact; it appears to have been real, with a 5 microsecond period and a quality factor for damped oscillation of about 4.

Discussion

We have found no evidence suggesting that sharp-tipped lightning rods are effective strike receptors when similarly-exposed, moderately blunt rods are in their vicinity. While lightning does strike sharp rods when no competing receptors are nearby, we find that the rate of electric field intensification for return stroke leader formation must be much greater for sharp rods than for blunter ones.

From this seven-year study, there are no indications that either of the so-called "early streamer emitting" devices created or emitted any effective early streamers or leaders.. In our tests, two "ESE" devices responded to nearby lightning about as did the sharp Franklin rods, none of which took a strike during this study.

It is worth noting that, after a large current emission from one of the rods, the electric fields produced by the charges in that emission appear to suppress any competing emissions from nearby rods. This effect is shown in Figures 2 and 3 when the emissions from the 19-mm diameter rod were dominant and in Figure 4
when the charge transfer from the Franklin rod was 12-fold greater than that of both competing rods even though its streamers and leaders did not connect to the descending negative leader that struck a tree at a distance of 30 meters.

Since it is now well established that the emissions from sharp rods do not neutralize the electricity in thunderclouds and that they do not prevent the occurrence of lightning, the original reason for having sharp tips on lightning rods is demonstrably not valid. It appears that Benjamin Franklin's significant contribution to lightning protection was his suggestion for erecting grounded metal rods to provide preferential paths to Earth for lightning. In retrospect, Franklin's method for providing this protection has been made less effective than it could be by his urging that the tip of lightning rods be sharpened; our data show that his rods would provide better protection if they were not so effective in limiting the strength of the local electric fields.

Conclusions

Our field experiments and our analyses indicate that the strike-reception probabilities of Benjamin Franklin's rods are greatly increased when their tips are made moderately blunt. (For recommended tip-height to tip-diameter ratios, see *Moore et al.* [1999].)

Acknowledgments

We thank East Coast Lightning Equipment, Inc., A-C Lightning Security, Robbins Lightning, Inc., Advanced Lightning Technology, Inc., Maxwell Lightning Protection of Florida Company and Bonded Lightning Protection of Florida Company for the support that made these digitizer studies possible, and Richard Setchell, Wisonsin Electric Power Company, for providing the computers used in this study. We also thank the other members of the lightning protection industry for their earlier support of this research.

Bibliography

***Berio,* 1970**

Berio, G, Use of ionization in air for lightning protection, *Isotopes and Radiation Technology*, *8*, 178-180, 1970.

***Franklin,* 1753**

Franklin, B., How to secure Houses &c. from Lightning, *Poor Richard's Almanac*, 1753, reproduced in *Experiments & Observations 0f Electricity (1774)*, I. B. Cohen, ed., Harvard University Press Cambridge, pp. 129-130, 1941.

***Franklin*, 1767**

Franklin, B., Of Lightning, and the Method (now used in America) of securing Buildings and Persons from its mischievous Effects, Letter XXIV, 1767, reproduced in *Experiments & Observations 0f Electricity (1774)*, I. B. Cohen, ed., Harvard University Press Cambridge , pp. 388-392, 1941.

***Kip*, 1938**

Kip, A.F., Positive-point-to-plane discharge in air at atmospheric pressure, *Phys. Rev., 54*, 139-146, 1938.

***Moore et al*, 1999**

Moore, C.B., W. Rison, J.A. Mathis, and G.D. Aulich, Lightning rod improvement studies, *J. Appl. Meteorol.*, in press, 1999.

***Phelps*, 1971**

Phelps, C.T., Field-enhanced propagation of corona streamers, *J. Geophys. Res.*, *76*, 5799-5806, 1971.

List of Figures

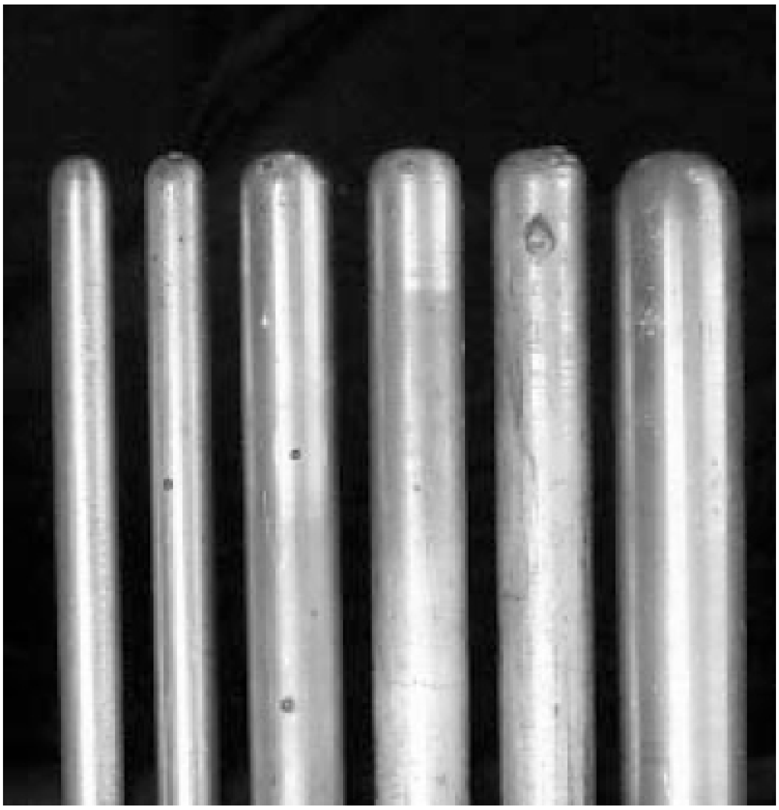


Figure 1: Photograph of six blunt aluminum lightning rods, each of which has been struck by lightning. The two rods on the left were 12.7-mm in diameter, the rod on the right was 25.4-mm in diameter and the diameters of the other rods were 19 mm.

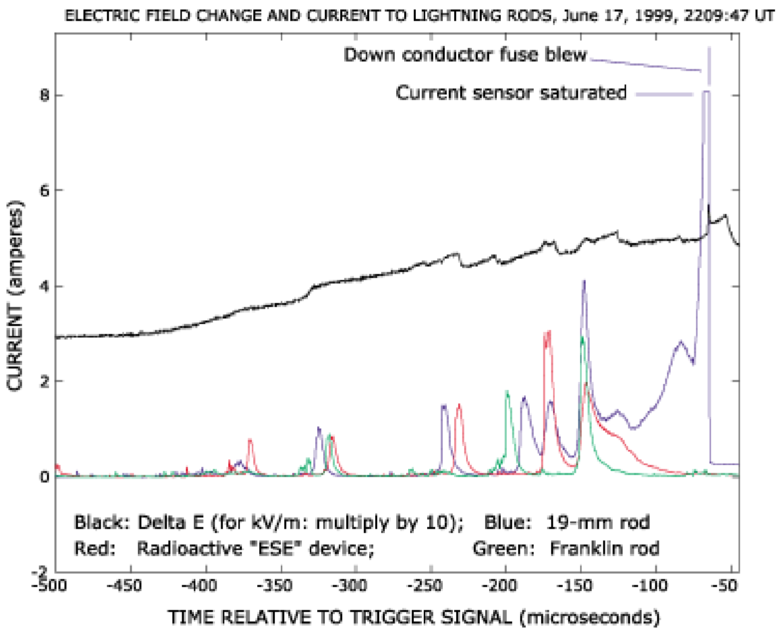


Figure 2: Plots of the early electric field changes and of the currents that flowed from three lightning rods mounted on 6-m high masts above Kiva II on South Baldy Peak when lightning struck the 19-mm diameter blunt rod (June 17, 1999).

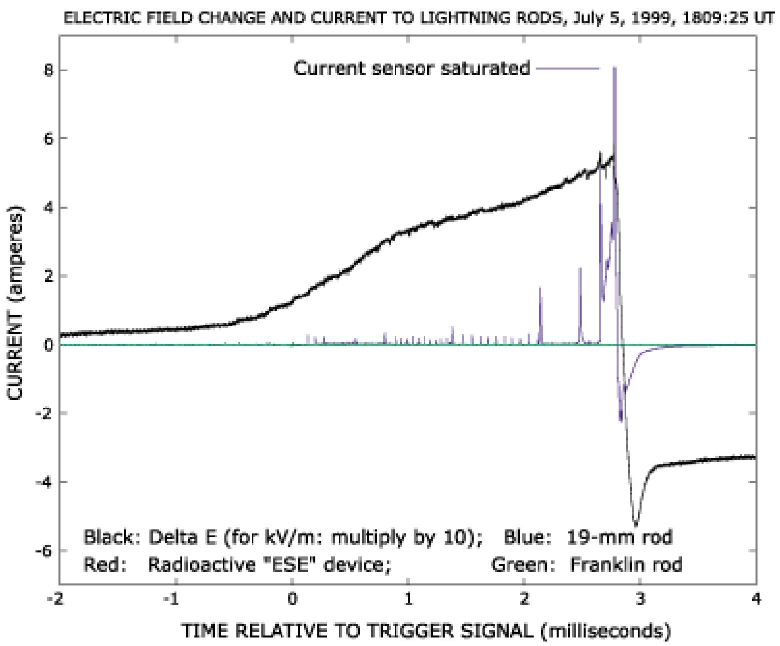


Figure 3: Plots of the electric field changes and of the currents that flowed from three lightning rods mounted on 6-m high masts above Kiva II on South Baldy Peak when lightning struck a 12.7-mm diameter blunt rod located 42-m

WNW of Kiva II (July 5, 1999).

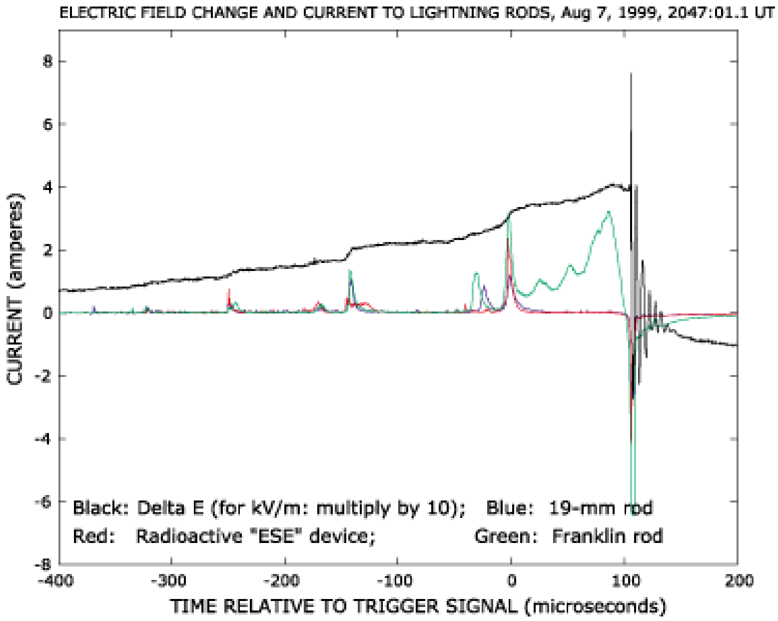
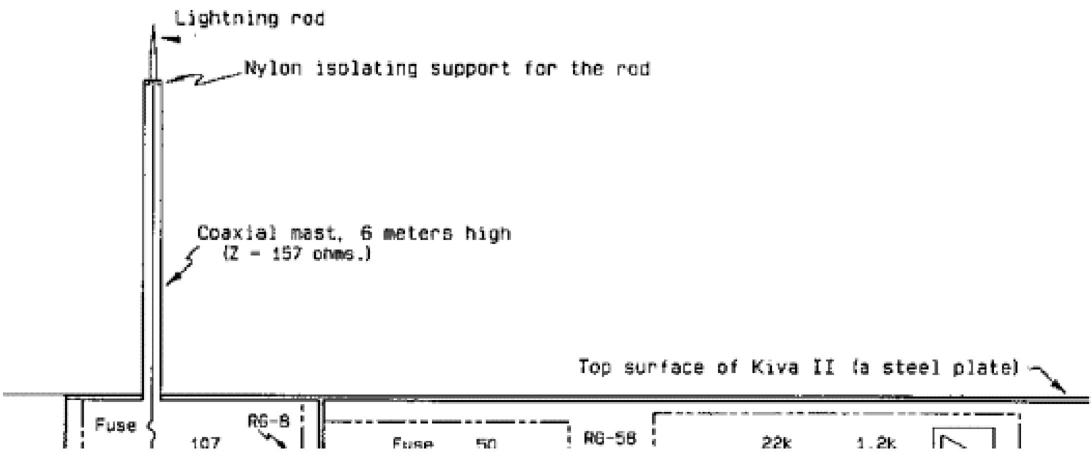
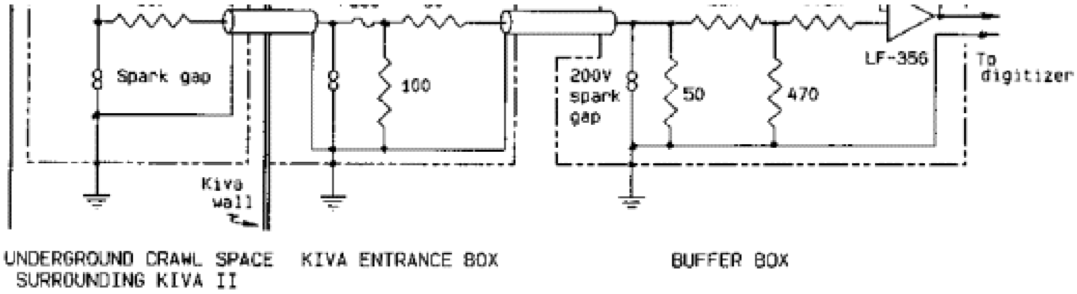


Figure 4: Plots of the electric field changes and of the currents that flowed from three lightning rods mounted on 6-m high masts above Kiva II on South Baldy Peak when rocket-initiated lightning struck a pine tree located 33-m NNE of Kiva II (August 7, 1999).

Supplementary figures for "Measurements of Lightning Rod Responses to Nearby Strikes"

- Schematic of protection circuitry.
- Picture of lightning rods installed at Kiva II.




Spark gap
Kiva wall
100
200V spark gap
50
470
LF-356
To digitizer
UNDERGROUND CRAWL SPACE SURROUNDING KIVA II
KIVA ENTRANCE BOX
BUFFER BOX