National Radio Astronomy Observatory
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VLA Electronics Memo No. 232

Lightning Protection for Waveguide

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August 20, 1998

Summary:

How is the VLA waveguide protected from lightning? The original passive cathodic protection system, a zinc ribbon, provided lightning protection as well as corrosion protection. Where the ribbon has eroded away, is the waveguide adequately protected?

Background:

Data and control communication between VLA antenna and Control Building uses a 60 mm diameter TE01 mode waveguide manufactured by Furukawa Electric Company. The waveguide is constructed of 0.26" thick steel tube with an inner conducting surface of helically wound fine copper wire. The copper wire is insulated from the steel tube by an epoxy-based dielectric layer. The outer surface of the steel tube is coated with polyethylene over an asphalt-butyl blend primer and adhesive. Compromise of the waveguide on one of the array arms would result in the loss of use of up to 9 antennas for several days until the damaged section could be excavated and replaced.

To prevent corrosion of the waveguide steel jacket in the event the polyethylene coating developed a leak, a pair of zinc ribbons was buried 1' below the surface, 2' apart, and parallel to the waveguide, one ribbon on each side of the waveguide. The plan was for the zinc to serve as a sacrificial anode in a passive cathodic protection system. Measurements showed the passive system provided inadequate protection so an impressed current cathodic protection system was installed in the early 80's. With the new system, sacrificial anodes with an applied voltage replaced the corrosion protection function of the zinc wire, though Pacific Corrosion Research during an inspection in 1994 recommended maintaining the passive system in a few isolated areas where the impressed potentials are weak.

But Bechtel Engineering in their 1973 report on the waveguide system describe another function for the zinc ribbons: lightning protection. Just as a ground wire strung above power transmission lines provides a zone of protection for aerial lines, a buried counterpoise provides protection for underground pipes and cabling underneath. Lightning currents tend to follow the grounded wire first protecting the cabling or waveguide below.

Lightning hazard to the Waveguide:

Lightning is a hazard at the VLA. As recently as 1997, a 30,000 amp strike near the Control Building did thousands of dollars in damage to electronic circuitry. Lightning has been observed striking on or near the antennas; such an event is not unusual during the thunderstorm season. Isokeraunic maps show that the VLA area can expect 50 mean annual days of thunderstorm weather each year. No study has been made of the number and size of strikes at the VLA, but a study of the strike in 1997 showed dozens of nearby strikes during a single storm. 200,000 amp strikes have been reported in other areas of the world.

Dr. Martin Uman, a lightning researcher at the University of Florida rocket-triggered lightning facility, reports that when seeking ground, lightning passes through soil as easily as air. Heating from lightning currents through sandy soil forms a crusty channel called a fulgerite. With the help of archeology students, Uman has unearthed fulgerites over 10' long leading from surface to a grounded conductor buried in the soil. Uman confirms from his experimentation that a counterpoise above a buried cable provides lightning protection.

Bechtel attempts to predict the vulnerability of the waveguide to lightning damage in Appendix A of its Waveguide Report. The influence of the grounded rail running in parallel with waveguide and the presence of the grounded antennas, piers, and waveguide access holes, made calculation too difficult; but the Bechtel engineering judgement was that lightning strokes would reach the waveguide and might cause "erosion of material" that would be cumulative with time. As a result Bechtel recommended use of the zinc ribbon as a lightning protection counterpoise above the waveguide.

Condition of the Zinc ribbon; cost of repairing:

The zinc ribbons have eroded away or been broken at several locations across the array. To determine the condition of the zinc, one must disconnect the ribbon at waveguide access holes and measure the resistance from ribbon to ground with an ohmmeter. A high resistance indicates a break in the zinc. The measurements would have to be performed annually before lightning season if the lightning protection counterpoise were to be maintained correctly.

Zinc ribbon (11/32" x 13/32") costs $1.025/ft in 1000' rolls, but because the cathodic protection function of the zinc is no longer needed, at least for the most part, No. 2 gauge copper wire can be substituted at a cost of $0.52/ft in 5000 foot rolls. The copper wire should be insulated so that it does not interact with the impressed current cathodic protection system.

Assuming all of the zinc ribbon is in need of replacing, restoring the lightning protection system over 40 miles of waveguide with a single copper cable would cost $110,000 plus several man-weeks of labor to bury and connect the new copper wire. Measurements of the existing zinc grid may show the wire needed is substantially less than 40 miles.

What damage will the lightning cause?

Bechtel recommended installation of the lightning protection counterpoise for the waveguide, but then predicted the waveguide would survive a lightning discharge. Lightning can be expected to pass through the outside polyethylene coating and conduct through the steel to ground connections at the waveguide access holes. The lightning is not expected to penetrate through the steel to the copper wires because there are no reported cases of lightning penetrating steel tanks as thick as 3/16" and the waveguide tubing is 1/4" thick. Lightning current through the steel would cause heating which could in turn damage the polyethylene coating and/or distort the waveguide interior. Damage to the coating would expose the steel to corrosion while distorting the interior would render the waveguide immediately inoperable. From tests, Bechtel estimated the temperature rise of the steel necessary to distort the waveguide interior at 150 F. Using an estimated lightning discharge of 250 coulombs in 1 second at 100 kHz, Bechtel calculates a skin temperature rise of 66 F and a mean temperature rise of less than 2 F per second, below the level necessary for damage to the exterior coating or to the internal dielectric layer.

Dr. Martin Uman, the University of Florida researcher mentioned earlier, predicts from his experimentation that a direct lightning discharge to the waveguide would cause a pin hole burned in the outer insulation but no other damage. The impressed current cathodic protection system is intended to protect the waveguide from corrosion where the outer insulation is violated. Eventually water could leak through the hole and lift the mastic coating from the steel tubing. As explained in VLA Electronics Memo 231, the corrosion protection system will gradually become less effective as the water penetrates the holiday; but, based on our experience at CN7, the steel jacket will not be penetrated for many years. Indeed, the zinc counterpoise has been absent from the array in several areas for years with no damage reported as yet.

Although the waveguide may eventually be replaced with a fiber optic system, protection of the waveguide must remain top priority until the replacement is a reality.

Conclusions and Recommendations:

The cost of repairing the zinc ribbon lightning protection system at the VLA is large, even if copper wire is substituted. On the other hand, the consequences of damage to the waveguide are severe and unacceptable. Without the protection system, lightning will strike the waveguide and high currents will flow through the steel tube that forms the waveguide. Studies to date show that the waveguide will probably survive a lightning strike, but actual measurements would ease our minds. A section of waveguide could be tested at a rocket-triggered lightning facility at the University of Florida or Langmuir for under $10,000. The test would permit us to measure temperature rise, waveguide damage, and material erosion as a result of actual lightning strikes. The results of the test would make a decision to abandon the zinc ribbon protection system more objective.

Another test discussed after the damage to the waveguide at CN7 (VLA Electronics Memo 231) is to look for existing holes in the waveguide insulation with a holiday (hole) detector. The equipment, which is on hand, imposes a signal on the waveguide which can be detected from the surface where a hole or holiday exists. Comparing results between protected and unprotected sections of the waveguide and excavating and inspecting holidays may permit an objective evaluation of the need for lightning protection. We do not understand how to use the test equipment, but a consulting firm will help us with the tests for under $5000. Unprotected portions of the waveguide must be identified before the test.

This writer recommends that both tests be conducted before deciding on repair of the waveguide lightning protection system.