National Radio Astronomy Observatory
Socorro, NM 87801

EVLA Memorandum 41

Lightning Protection for Fiber Optic Cable

T. Baldwin

June 05, 2002

Summary

Double-armor triple-sheath fiber optic cable will be used to transmit the local oscillator frequencies, astronomical data, and antenna monitor and control signals to and from the antennas. Double-armor cable was selected for additional rodent and lightning protection. A major concern of this type of installation is the susceptibility of the cable to lightning damage. An estimation of the frequency and extent of damage to the cable is derived from the trouble history of similar installations, and essential grounding methods are described.

Trouble History

The most reliable indication of the need for lightning protection on a particular cable route is a history of lightning trouble. The recorded lightning trouble history for the cable route over a period of at least 10 years might suggest the need for lightning protection. The number of lightning induced troubles that have occurred on an existing cable route similar in location and length may reveal the effects on buried cable from the surrounding geophysical features.

A district manager for Qwest, Larry Hopkins, stated in phone conversations that none of Qwest's double-armor fiber optic cables installed in southwest New Mexico have experienced outages of any kind since this type of cable was initially installed in 1995. In these installations, the armors are grounded only at each splice point. The distance between splices is typically 18500 feet (5.6 km). The length is only limited by construction constraints, and longer lengths may be desirable. Mr. Hopkins stated that accidental cutting is by far the greatest concern.

Mr. Hopkins also stated that the copper telephone cables that serve the VLA have been in place since the early 1970's. These are single armor cables grounded at every pedestal. The problems that these cables experience are lightning, flood damage, backhoe damage, and gopher damage. The lightning damage is typically small pinholes in the sheath between the armor and core conductors, which create shorts when wet. Occasionally, direct strokes on a pedestal can damage about 5 feet (1.5 m) of cable. Qwest has never had to replace cable due to gopher damage or armor corrosion.

In a telephone conversation with a recently retired employee of AT&T, Tom Rehnert, we discussed a fiber optic cable installed along US Rt. 60 in 1992. The cable is single-armored, and is buried 3 feet deep. The cable is in lengths of about 3 miles (4.8 km), and is grounded about every 10 miles. Mr. Rehnert stated the cable never experienced any type of problem since it's installation. This cable system was designed for a 30-year life span.

In several conversations with long-time employees at the VLA, no lightning induced outage of our cabled systems has ever been reported. These cable systems have not experienced corrosion problems, although Rey Serna states that these cable systems would have the benefit of cathodic protection because they are bonded to the waveguide ground. Backhoe damage is by far the greatest concern.

Considering the history stated above, there seems to be little need for lightning protection beyond grounding and bonding at the splice locations.

Affect of Existing Buried Structures at the VLA

Existing buried structures at the VLA include the waveguide, the rail ground system, the antenna foundations and ground systems, and natural geophysical features. Some of these structures are significant in the protection and grounding of the fiber optic cables.

The waveguide and the rails run parallel to and within a few meters of the cable trench. They are bonded to the antenna grounding system and periodically grounded along their length. Aerial shield wires were also placed above the waveguide for lightning protection. Although these structures are not adequately positioned to shield the fiber cable in all situations, these structures and the other well-grounded structures along the trench line will provide lower resistivity to ground, thereby protecting the cables by dissipating surge currents more effectively in the immediate area of the strike and at the antennas.

The antennas are significant to the fiber optic cable system because large aboveground metal structures provide lightning protection at the ground level. The protection extends horizontally from the antenna to a distance equal to three times its height. This protection reduces the possibility that lightning might cause cable damage where the cable rises above grade level. Conversely, the widely separated conductive structures may increase the incidence of lightning strikes in the area, which could disrupt the cable grounding system. For this reason, proper bonding of all metallic structures near the fiber optic cable grounds must be ensured. It is assumed that sufficient grounding of the antenna structure during the original installation will provide less than 10 ohms to ground. This low resistance ground will provide greater current dissipation from the cable bond.

Natural geophysical features such as bedrock and high soil resistivity will cause a strike to travel further and dissipate more slowly. Since the cable sheath is not adequate to resist a near strike, some cable damage can be expected in these areas. Much of the soil along the cable route has high resistivity and the great distances between grounding points will cause high surge impedance, therefore large portions of the cable route may be subject to some damage. The trouble history in the area suggests this damage may not be significant. A description of the extent of damage is included below.

Estimation of Damage

Cable damage caused by lightning surges is difficult to predict except through the history of other cables buried in the area. Of those strokes that affect buried cable, only 5 percent is of the high-current type which is so destructive to installations. AT&T has demonstrated this in field studies. Additionally, cable sheaths are designed to provide low-resistance, high-current paths to ground for direct strokes with minimum or no damage. While arcing at the point of contact is a problem, induced voltages are the major concern. A good description by AT&T of surge induced damage to a cable with copper wires can be found below. This description can be adapted to the double-armor fiber optic cable to be used at the VLA where shield-to-shield voltage is the concern. The following is a description of induced damage, not a direct strike.

"The core-shield voltage will normally be maximum at the point where the surge current enters the shield. If breakdown between core and shield occurs at or near the stroke point the voltage would then drop to essentially zero and increase gradually with increasing distances away from the stroke point. The core-shield voltage will again build up but to a value substantially lower than it was at the stroke point before initial breakdown. However, the core-shield voltage will not exceed the dielectric strength of the insulation. If the original core-shield potential at the stroke point is quite high, it is probable that several punctures will occur along the cable. In trunk-type cables where all the pairs proceed from one terminal point to another with a minimum of side taps, lightning trouble is principally of the core-shield type. Core-shield voltage is essentially equal to the product of the surge current in the shield and dc resistance of the shield."

"Jackets may have substantial dielectric strength, but they do not provide effective protection against direct lightning strokes because the voltages associated with direct strokes will in most cases greatly exceed jacket dielectric strengths. After initial puncturing of the jacket, which occurs at or near the stroke point, subsequent puncturing is most probable. For buried cable, the higher stroke currents will produce punctures to such an extent that, from a surge standpoint, it may be considered essentially the same as a shield in direct contact with the soil."

"The resistivity of the soil in which a cable is buried will have a significant effect upon its lightning behavior with regard to direct strokes, earth potential gradients, and the rate at which current leaves the shield. The higher the soil resistivity, the more susceptible the cable to damage from strokes that produce extremely high voltage gradients in the soil near or across the path of the cable but do not necessarily arc to the cable."

The preceding paragraphs can be adapted to the cable type to be used at the VLA where shield-shield voltage is the subject rather than core-shield voltage. The cable to be used at the VLA is double-armored, and the cable is placed in typically highly resistive soil. The cable at the VLA would be subject to damage as described above, leaving pinhole punctures in the first sheath. If the shield-shield voltage is sufficient, the second sheath will also have pinhole damage to a lesser extent. The third sheath and the fiber would be undamaged. Although the armor has a protective coating, corrosion may cause further damage, but the protective coating and the bonded construction of the cable will prevent corrosion from spreading.

This conclusion is only valid for lightning induced surges. When a very near strike occurs, damage will most certainly occur from direct conduction.

A direct strike occurs when the lightning stroke contacts earth within the arc distance from the cable. This distance is measured horizontally along the surface of the earth, and is estimated as follows.

$$d_{arc} = 0.8\sqrt{\rho}$$

Where ρ is soil resistivity in meter-ohms, and d_{arc} is the arc distance in feet.

The average soil resistivity at the VLA is less than 180 cm-Ω and the greatest value is 545 cm-Ω, according to data compiled from many borings. An AT&T source shows a higher average soil resistivity of 125 m-Ω. Using an average 125 m-Ω, $d_{arc} = 8.9$ feet (or 2.75 meters), or a path twice this width centered over the cable. When lightning strikes earth within this zone, damage to the cable will most certainly occur but would be localized to the strike area.

Ninety-five percent of all lightning stroke crest currents to buried structures are less than 100 kA. Common fiber optic cable tests include EIA/TIA FOTP-181, "Lightning Damage Susceptibility Test for Optic Cables with Metallic Components". This is a sandbox test that exposes the first armor and subjects the cable to a 105kA simulated strike. The cables used at the VLA must be tested according to FOTP-181 at the 105 kA level, and the fibers must remain continuous after the test.

A best guess about the extent of damage to the fiber optic cables at the VLA can be derived from the information above. Damage will occur to the outer sheath during induced surges, and possibly to the first armor. The secondary armor and sheaths will remain in relatively good condition. Additionally, local damage from direct strikes may occur, but in no case should the third sheath or the fibers be damaged. In the event that fiber damage does occur, the location of the damage can be located and the section of cable replaced quickly, certainly within one day if adequate provisions are made prior to the incident.

Possible Protection Measures

Shielding, grounding, and cable spacing are common protection methods which could be employed at the VLA.

Shielding

Shielding refers to the practice of running one or more, typically two, bare conductors parallel to and over the cable to be protected. The shield conductors essentially intercept a lightning stroke that would otherwise arc to the communication cable. A single copper 6 AWG conductor over the entire length of the cable trench, or 41.25 miles (66 km), would cost at least $24,000. The trouble history in the area suggests the cost is not warranted.

Spacing and Grounding

A combination of spacing and grounding are critical to the protection of any installation. The National Electric Code and the various electrical safety codes require that all non-current-carrying metal parts must be bonded to ground. Additionally, if proper spacing between grounded parts of great length is not maintained, such as the case with cables of different systems, then arcing can occur. Where arcing is a possibility, a properly placed bond will reduce the risk.

The ground resistance required by code is 25 Ω, but the telecommunication industry has found through experience that this is not sufficient because of the great lengths of cable involved. Industry practice is to set a goal of 5 Ω to ground, but compromise up to 10 Ω where the lower value is difficult to achieve.

Where power and telecommunication cables are in separate trenches more than 3 feet apart, a bond must be made at all above-ground terminals which are located within 10 feet of any above-ground apparatus. An 18 inch separation between power and telecommunication cable is a minimum spacing compromise regardless of voltage range.

Where separation is less than 3 feet, grounds of the two systems must be bonded

1. Not more than 1000 feet apart.
2. Nearest the transformer, to the transformer primary or secondary neutral.
3. At all above ground closures which are within 10 feet of any above-ground power apparatus.

The only locations throughout the planned cable route where power and fiber optic cables will have a separation less than 3 feet is near the Control Building entrance, and at various crossing points along the array. Typically, power to fiber cable spacing will be greater than 20 feet.

The fiber optic cables entering the Control Building will be enclosed in heavy wall PVC conduit, minimizing the exposure to power. The fiber cables will be bonded to a common grounding point just inside the building, and bonded to the transformer ground and the building counterpoise within ten feet outside. The cable shield-to-ground resistance with this arrangement should be less than 10 Ω at the Control Building cable entrance.

There are several locations along the array where fiber optic cable will cross power cables. The separation between these two systems should be 18 inches, minimum, preferably three feet.

Fiber optic cables should not be bonded in manholes where the cable is only pulled through. Where a splice occurs, the fiber optic cables will be bonded to the waveguide ground in the antenna manholes. The waveguide ground is presently bonded to the antenna counterpoise, the track ground, and the power ground. Joint use of manholes with power shall not occur. The cable shield-to-ground resistance with this arrangement should be less than 10 Ω in the manholes.

Fiber optic cables shall be bonded to the Antenna Pad Enclosure at the antenna that they serve. Antenna Pad Enclosures shall be bonded back to the manhole ground.

All bonds shall be a No. 6 AWG copper conductor.

Additional grounding where bonding is not possible

When a cable is broken between manholes and bonding to existing structures is not possible, additional shielding will be necessary. A ground rod or two is not sufficient because of the high soil resistivity at the VLA. Shielding in these cases takes the form of either a buried counterpoise wire bonded to the cable shield, or buried shield wires placed well above the cable. 6 AWG copper wire is sufficient for either configuration.

To decide which configuration to use, and how long the wires should be, the ground resistance and surge impedance response time should be known. The dc ground resistance of a wire in soil with a certain resistivity follows the equation

$$R = \frac{\rho}{\pi L}\left[\ln\left(\frac{L}{\sqrt{4d^2}}\right) + 1\right]$$

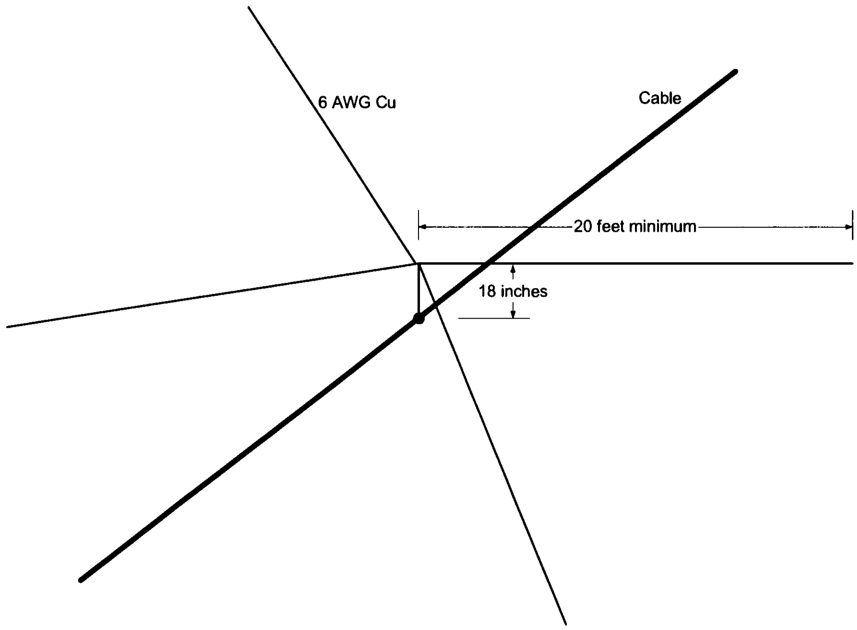
Where R = the ground resistance,
d = the depth of the wire,
L = the length of the wire,
ρ = the soil resistivity.

Using this equation, a shield wire 80 ft (25 m) long placed in soil with resistivity equal to 150 m-Ω has a dc ground resistance equal to 4.5 Ω.

A high surge current travels in a wire at 33% the speed of light to the end of the wire and reflects back to the starting point. During this time the surge impedance of the wire drops from about 200 Ω to the dc resistance. This means the surge impedance in an 80 ft wire will not reach the dc resistance level for 250 ns. If a typical lightning induced surge will rise to peak voltage in 15 μs, the response time of the system is sixty times faster than the surge.

An alternate configuration is a four-leg star counterpoise as shown below. The ground resistance of such a counterpoise with four legs of 20 ft (6 m) each is still 4.5 Ω. The time to reduce the surge impedance to the dc resistance level is about 60 ns, or 250 times faster than the surge. There is insignificant advantage in using more than four legs.

Therefore, one of these two configurations is recommended, but a four-leg counterpoise is preferred. The wire used must be 6 AWG copper, the total length must be at least 80 feet long (25 meters), and it must be buried 18 inches (0.45 m) above the cable.



Conclusions

Double-armor fiber optic cable will provide a long service lifetime and very goo protection from lightning induced surges, and even adequate protection from direct strikes. To provide good service, the cable armors must be bonded to all available grounding structures. Where no such grounding structures are available, additional grounding such as that described above must be used.

Double-armor fiber optic cable will also provide excellent protection against rodent damage and corrosion.

If damage does occur, the damaged section can be located and replaced with a minimum of downtime. It is highly recommended that an Emergency Restoration Procedure be implemented, and that thorough installation records are created, so that trouble spots can be quickly located and repaired.

References

Bechtel Engineering Report, 1973.
Fiber Optical Cable Armored with Coated Steel for Wildlife Protection, Kenneth E. Bov
The Dow Chemical Company, August, 1998.
Lightning and Optical Fiber Cables, Corning Cable Systems Application Note AEN 5.
National Electric Code 2002 Edition, NFPA
Standard for the Installation of Lightning Protection Systems 2000 Edition, NFPA 780.
Telecommunication Electrical Protection, AT&T Technologies, Inc., 1985.
VLA Memo 232, Lightning Protection for Waveguide, C. Janes, August, 1998.