White Paper

Lightning Protection for Cellular Tower Mounted Electronics

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1. Introduction

Lightning happens! While it can be a spectacular phenomenon to witness, it can also cause damage to property, structures, and even be fatal to human life if not respected. Without a doubt, expenses from lightning damage can be substantial—especially for companies whose equipment is installed on tall structures (since lightning tends to strike taller objects). The wireless antenna industry is particularly at risk with its multitude of towers. With antenna equipment leaning more toward sophisticated designs (many with integrated electronics), protecting the electronics adds another layer of costs to the overall expenditures for a wireless site. These extensive overheads can make or break a business opportunity in today's highly competitive arena. Antenna OEMs are faced with the importance to determine whether lightning protection is required and the level needed, when considering new business ventures. This paper provides factors to consider, as well as recommendations.

2. Lightning Background

Cloud-to-ground lightning strikes usually originate from thunder clouds in the form of a *leader*, carrying negative charges traveling towards the Earth in a stepped fashion. This negative downward leader provokes upward-moving positive streamers from objects protruding from the ground (objects from the ground form intensified electric fields beneath the negative downward leader). The upward streamers may form into a positive leader, which then connects to the downward negative leader. The connection acts as a huge *switch closure* and forges a path for the negative charges to drain to the Earth. This type of lightning is referred to as *negative lightning*. Positive lightning (a leader carrying positive charges from a thunder cloud down towards the Earth) occurs on a less frequent basis, but consists of a higher level of energy.

Determining the most likely object to project the successful upward-bound leader will be crucial for the placement and protection of antenna towers. The physics of lightning show that upward streamers only occur when the local electric fields are very strong, and that curved conductive surfaces intensify any ambient electric fields. Elevated structures, such as antenna towers, provide these characteristics and produce the ideal environment to attract lightning. Therefore, it becomes apparent that proper lightning dissipation be designed into the towers, while considering factors that can diminish the probability of a direct lightning strike.

3. Protection Factors

Certain factors will help evaluate the need for protection for tower mounted electronics.

- Lightning frequency and probability
- Structure height
- Installation landscape
- Structure grounding
- Equipment placement

3.1 Lightning Frequency and Probability

Figure 1 illustrates the number of lightning strikes in the U.S. from 1996 to 2000. Data collected establishes the flash density (number of discharges per square kilometer per year) for each area. The probability of lightning can be calculated by multiplying the flash density by the attractive area of the structure [1, section 3.5.1]. The attractive area of a structure reflects the ground area surrounding the structure that is susceptible to lightning. The attractive area is exponentially proportional to the structure's height. This indicates that the higher the structure, the more likelihood it will trigger lightning.

From the theories mentioned above, similar antenna towers installed in an area with low flash density will probably need little to no protection, while those in a high frequency area will require a higher level of protection. The level of protection is proportional to the need for protection. It is recommended that areas with flash density above 4 should be considered high risk and a more stringent level of protection should be implemented.

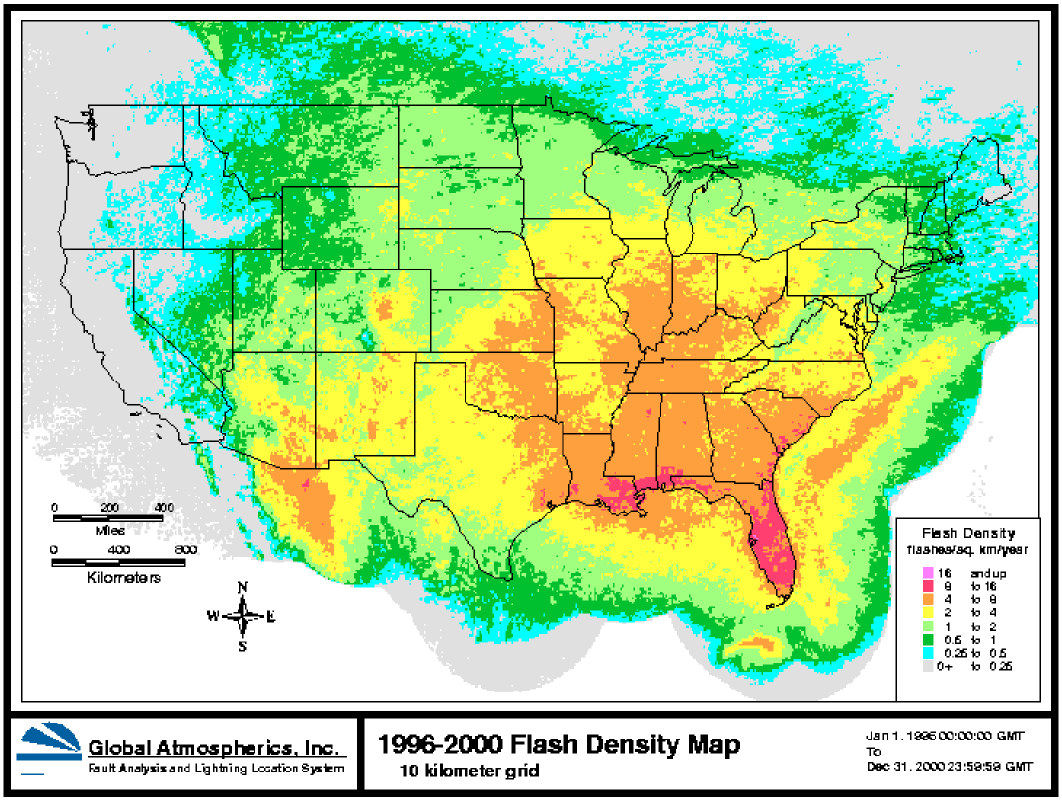

Figure 1. USA Flash Density Map. Courtesy of Global Atmospherics, Inc.

3.2 Structure Height

As indicated above, lightning tends to strike taller structures due to the intense concentration of electric fields present at their most elevated points (triggering a lightning path) [1, section 3.3]. Interestingly, collected data shows that lightning does not usually strike structures under 100 meters in height [1, section 3.5]. Cellular antenna towers are typically 20–75 meters (50–200 feet) in height, which makes them less susceptible to lightning strikes.

3.3 Installation Landscape

Another factor to be considered is that most city antenna towers are erected in landscapes where other tall structures (such as buildings, light poles, power towers, etc) are also located. These tall structures *compete* as lightning triggers; therefore, attracting lightning to themselves, as well. Taller structures also provide a *cone of protection* [1, section 3.5.2], which provides protection for shorter elements in its *cone* from a direct strike. As long as the antenna tower is less in height than its counterparts, its probability of getting a strike is much less than if it was the only tall structure standing in the landscape.

3.4 Structure Grounding

The proper grounding of the antenna tower and ground station, adds another factor to protecting electronics. This is the most important factor to consider. If the tower and the ground station are not properly grounded, no amount of protection will suffice if the tower suffers a direct strike. The whole tower should be the *down conductor* that will dissipate the lightning energy. The idea here is to make the whole tower the least impedance path to ground. Once the energy traverses down the tower, it needs to be divided down using ground rings and diverters.

A lightning strike to the tower can also produce Ground Potential Rise (GPR) where the lightning energy causes the whole grounding system to elevate in potential. GPR can damage electronic equipment if the equipment is not bonded (connected) to a low impedance, single point ground [3].

Andrew Corporation document SP40-09 also provides specifications for grounding; while the document does not address tower grounding specifically, it offers valuable guidelines that are worth reviewing.

3.5 Equipment Placement

The tower design needs to consider placement of antennas and associated electronics. Normally, antennas and electronics should be placed significantly below the highest point on the structure for reasons stated above. The point here is to make the tower itself the point for direct strike and not the equipment. Situations where the antennas serve as the highest point will demand higher levels of protection.

4. Protection Principles

The principles of protection are simple, and in many cases cost effective. Three principles that apply to tower mounted electronics and ground station equipment:

- Control, by dividing energy before it gets to the equipment
- Implement a single point, low impedance system ground for electronics
- Isolate electrical equipment

4.1 Control by Dividing Energy

Lightning energy seeks the lowest impedance to ground. Since this energy can induce surges upwards of 3000 amps and 60,000 volts [2], it is preferable to control the energy by dividing it into more manageable quantities. The desired effect here is to provide multiple paths for the energy to dissipate. This provides several advantages.

- Multiple paths remove risks associated with a single point failure. (e.g., If a single path to ground fails, some to all of the energy would have to be absorbed in the equipment. With multiple paths, the energy to be absorbed will be minimized.)
- Multiple paths require less current per path, which equates to smaller, less expensive conductors. By taking advantage of the surface movement of electrons, solutions can be quite cost effective by using wider, smaller gauge conductors (braids) instead of thick heavy gauge ones.
- Multiple paths lower overall impedance to ground.

Depending on the factors discussed above, implementation can be as simple as using wire braids soldered to the shield of cables and secured to the tower or as complex as using surge arresting systems. All of these devices provide paths to ground as their main function.

4.2 Low Impedance, Single Point System Ground

The purpose of having a low impedance, single point system ground is to equalize all potentials. By having a single point ground, all electronics in the system are kept at the same potential. Combined with a low impedance path, ground is close to zero potential and not at a damaging level. The National Electric Code specifies impedance of less than 25 ohms, while the IEEE recommends less than 5 ohms for sensitive electronic equipment [2].

4.3 Isolation

For the highest risk installations, isolation of tower and ground station paths will need to be considered. Isolation prevents the transfer of energy directly, therefore providing maximum protection. Optical technology and magnetics are often used to isolate components.

5. Recommendations for Tower Mounted Electronics

The recommendations shown below point to the risk level based on flash density. The recommendations set forth in this section apply to tower mounted electronics with the following prerequisites:

- Tower is not the highest structure in the landscape.
- Tower is less than 100 meters in height.
- Tower is properly grounded and serves as least impedance path to earth ground. Low-impedance single point ground for electronics should be less than 5 ohms.
- Electronics and enclosures are mounted at least 2 meters below the highest point of the tower.

If these prerequisites are not met (particularly for medium risk), it is recommended to use the same protection as suggested for the high level.

Flash Density	Risk/Level of Protection	Recommendation of Protection
0 to less than 1	Low	Built-in protection in electronics is adequate. Recommended cable grounding: 1) at top of tower; 2) at bottom of tower; 3) at the entrance to the ground station shelter
1 to less than 4	Medium	All recommendations for low risk, plus: 1) cable grounding every 60 meters; 2) cable grounding at every antenna sector; 3) surge arrestors for ground station electronics
4 and above	High	All recommendations for medium risk, plus: 1) surge arrestors at tower top
Exceptions: 1) Tower height >100 meters; 2) lone standing tower in >4 flash density area	Highest	All recommendations for high risk, plus: 1) surge arrestors every 30 meters; 2) isolation

Note: The lightning strike probability calculation (attractive area x flash density) of a 100 meter high structure is used for the table above. Since the structure height stays fixed, only the flash density is significant.

6. Conclusion

For the wireless antenna industry, lightning protection has become even more necessary as a growing number of sophisticated electronic equipment is mounted on towers, which are more susceptible to direct strikes. Determining the level of protection that makes business sense requires considering factors that can reduce the probability for lightning strikes and decrease the level of protection; in turn, lower the overall cost of tower mounted systems.

7. References

[1] MIL-HDBK-419A, "GROUNDING, BONDING, AND SHIELDING FOR ELECTRONIC EQUIPMENTS AND FACILITIES", Military Handbook, December 1987.

[2] "Grounding and Lightning Protection Guidelines and Specifications for Communication Shelters", Publication SP40-09, Andrew Corporation, January 1992.

[3] "Getting Grounded", Ernest M. Duckworth, Jr., P.E., Mobile Radio Techonology Magazine.

[4] "Lightning Protection for Telecommunication Facilities", Richard Kithil, National Lightning Safety Institute, April 2006.

[5] Structural Lightning Safety, www.lightningsafety.com.

8. Appendix

The following figures illustrate Andrew Corporation tower mounted Antennas and Teletilt® electronics in various configurations. Each configuration indicates the lightning protection level recommended from low to high.

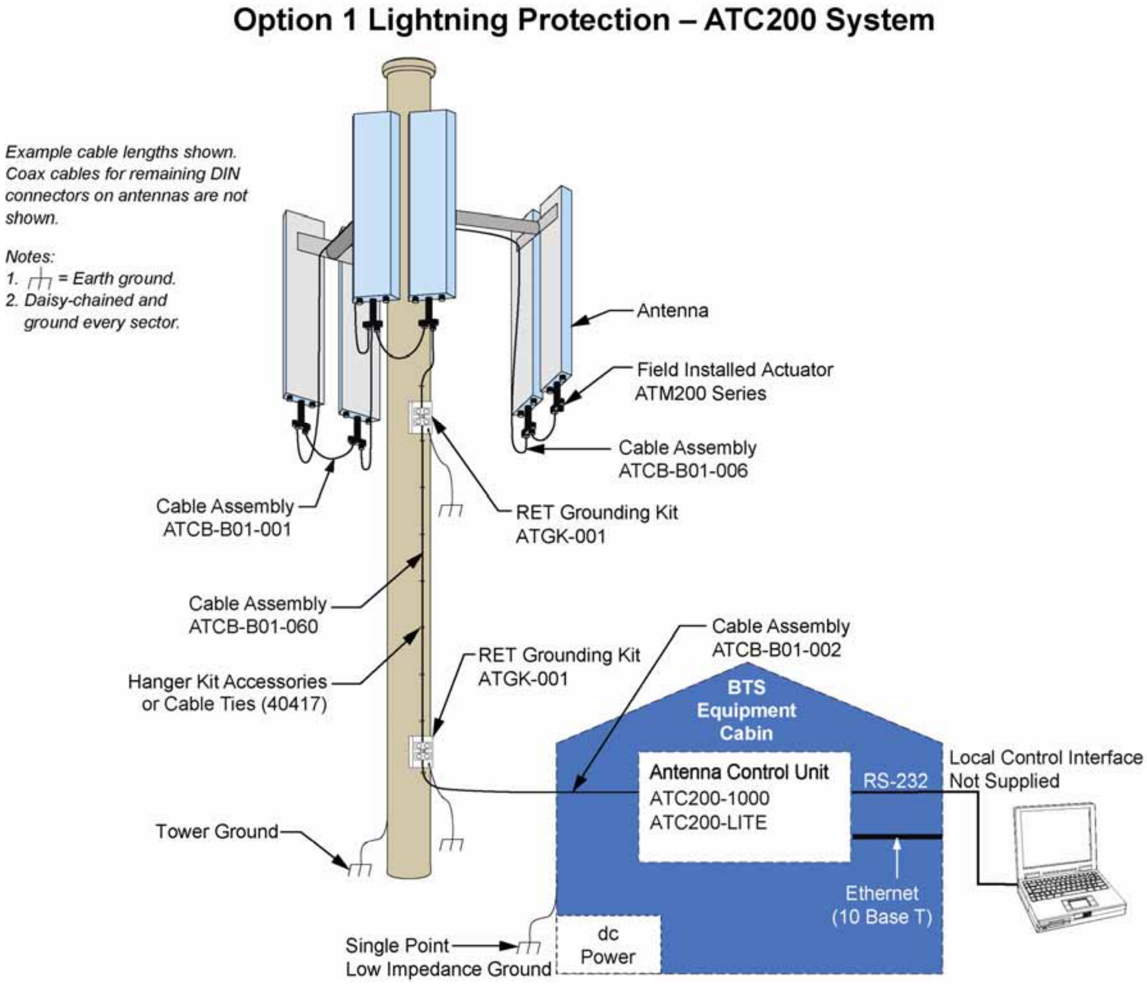

Figure 2. Antenna with RET, Low Protection Level.

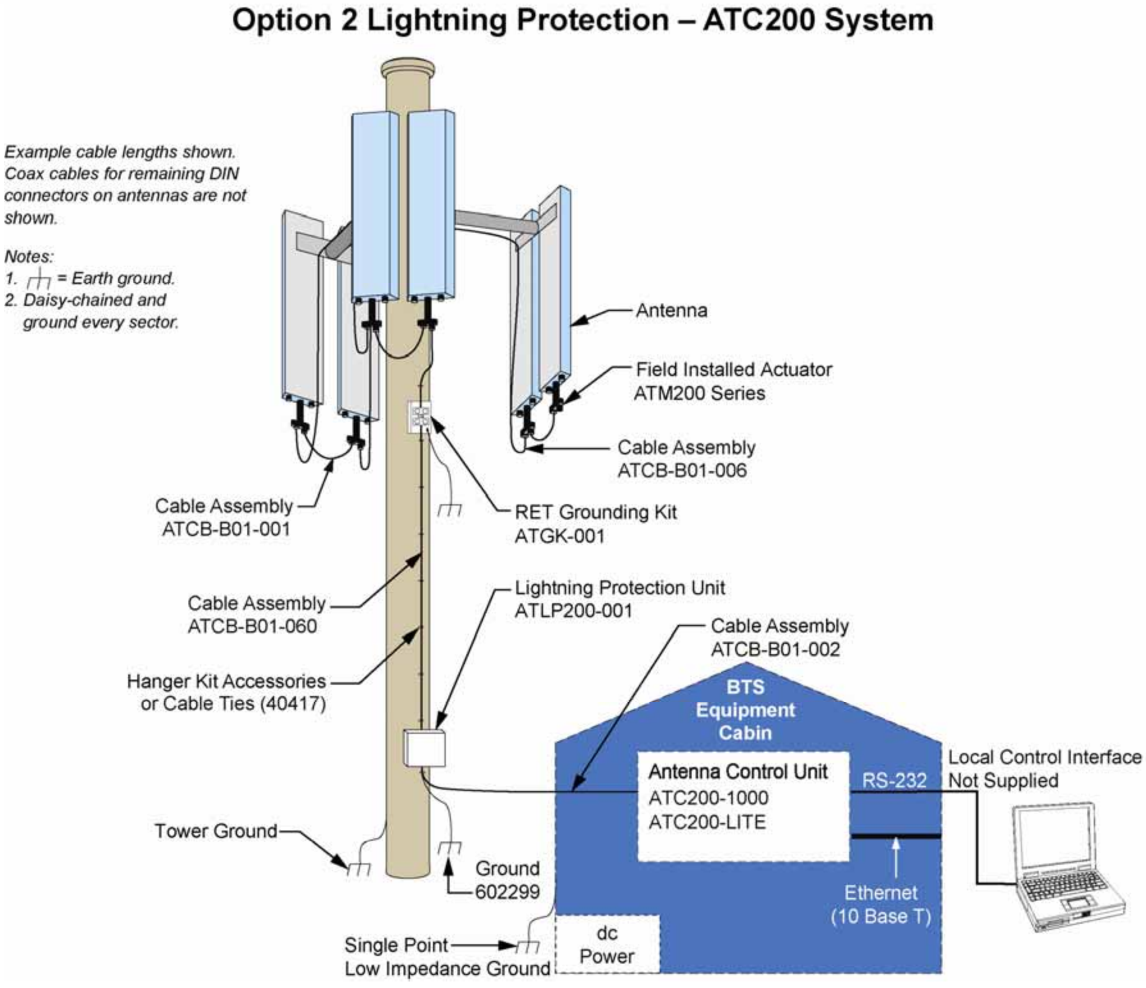

Figure 3. Antenna with RET, Medium Protection Level.

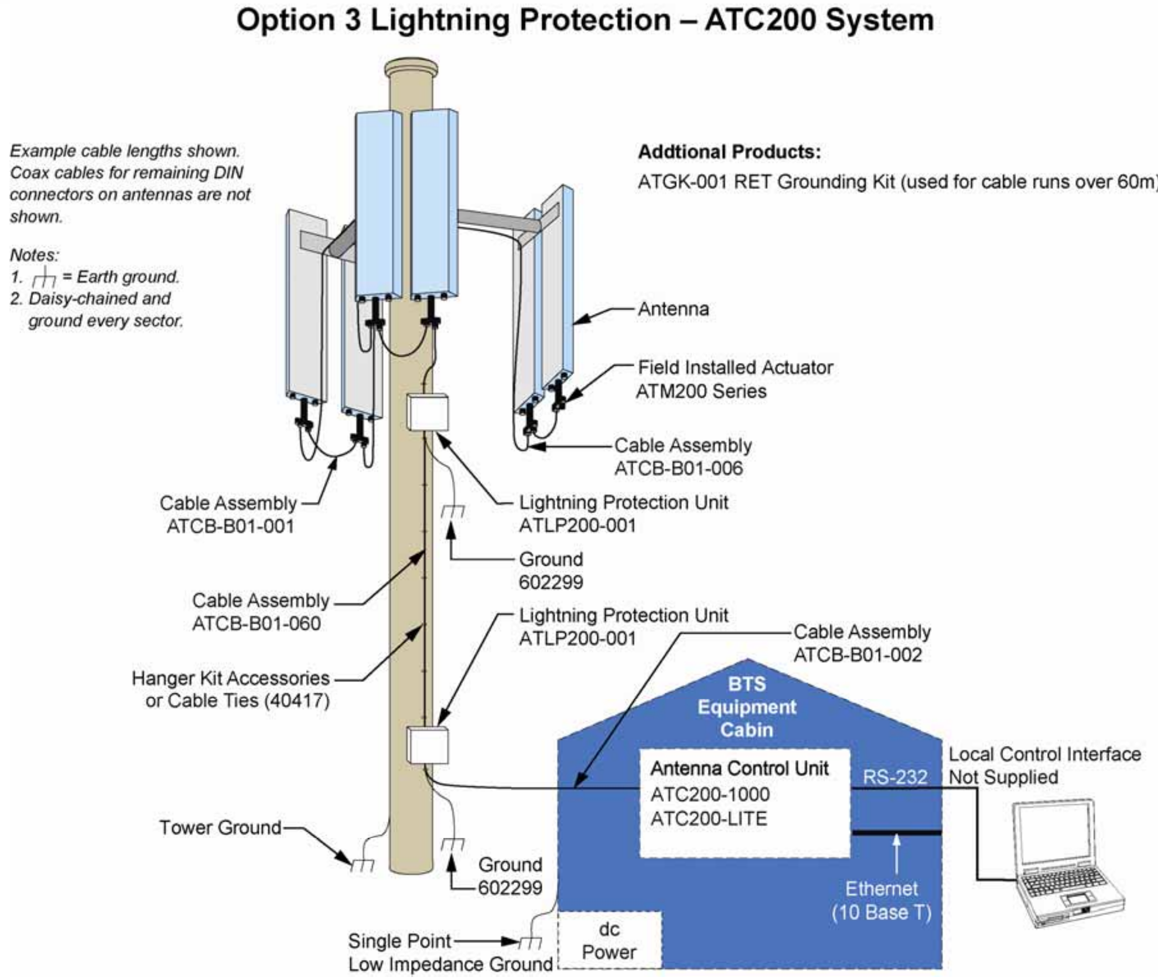

Figure 4. Antenna with RET, High Protection Level.

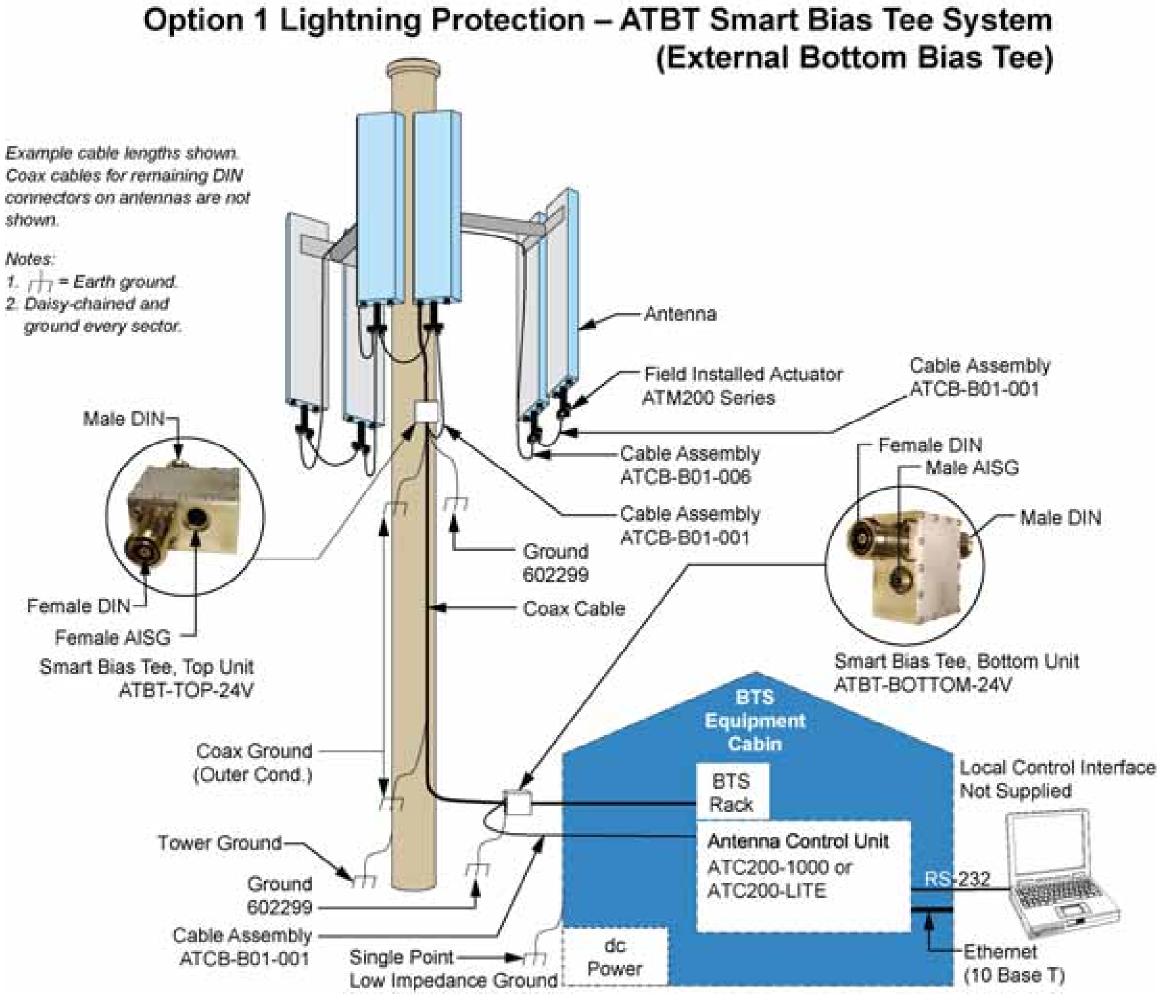

Figure 5. Antenna with RET/Bias-Tee (Outside BTS), Low Protection Level.

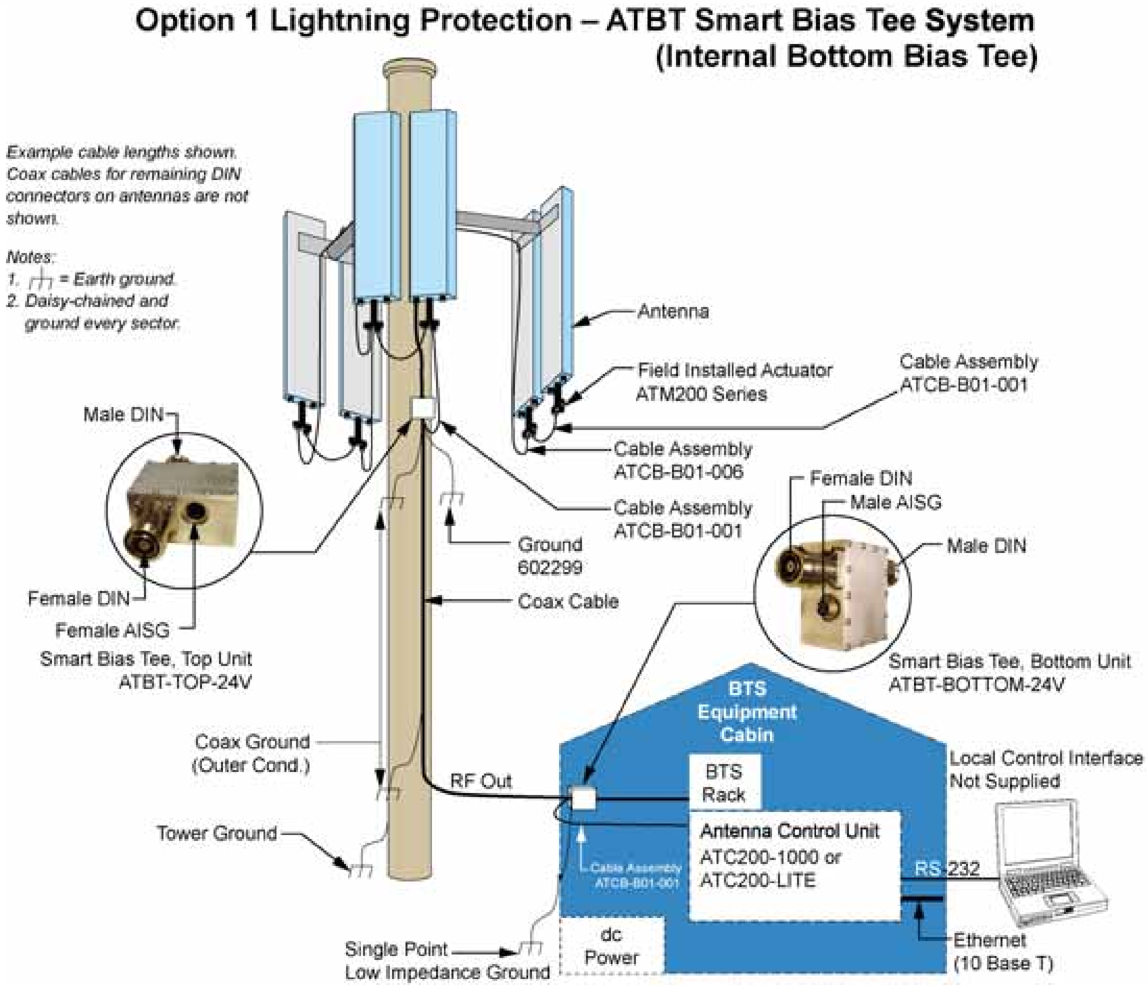

Figure 6. Antenna with RET/Bias-Tee (Inside BTS), Low Protection Level.

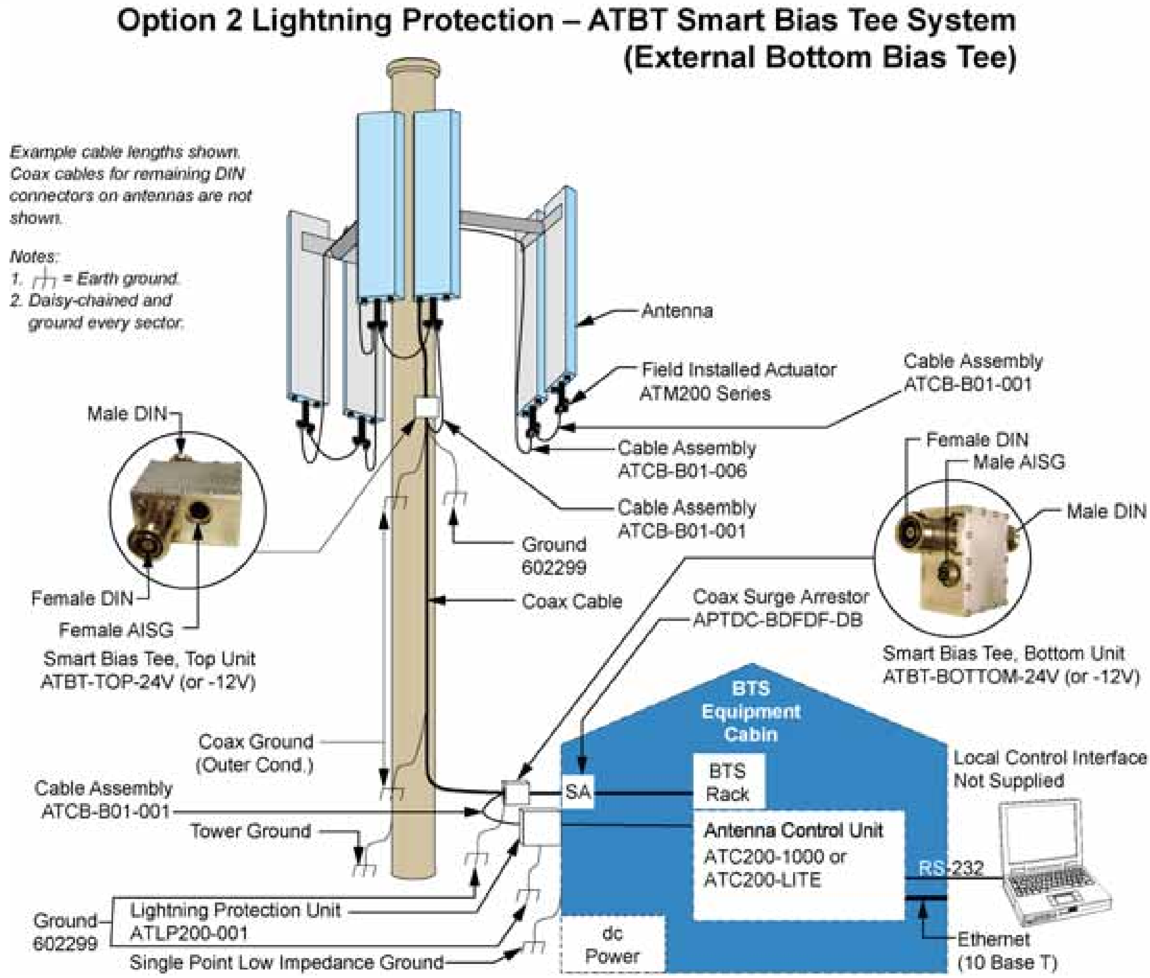

Figure 7. Antenna with RET/Smart Bias Tee (Outside BTS), Medium Protection Level.

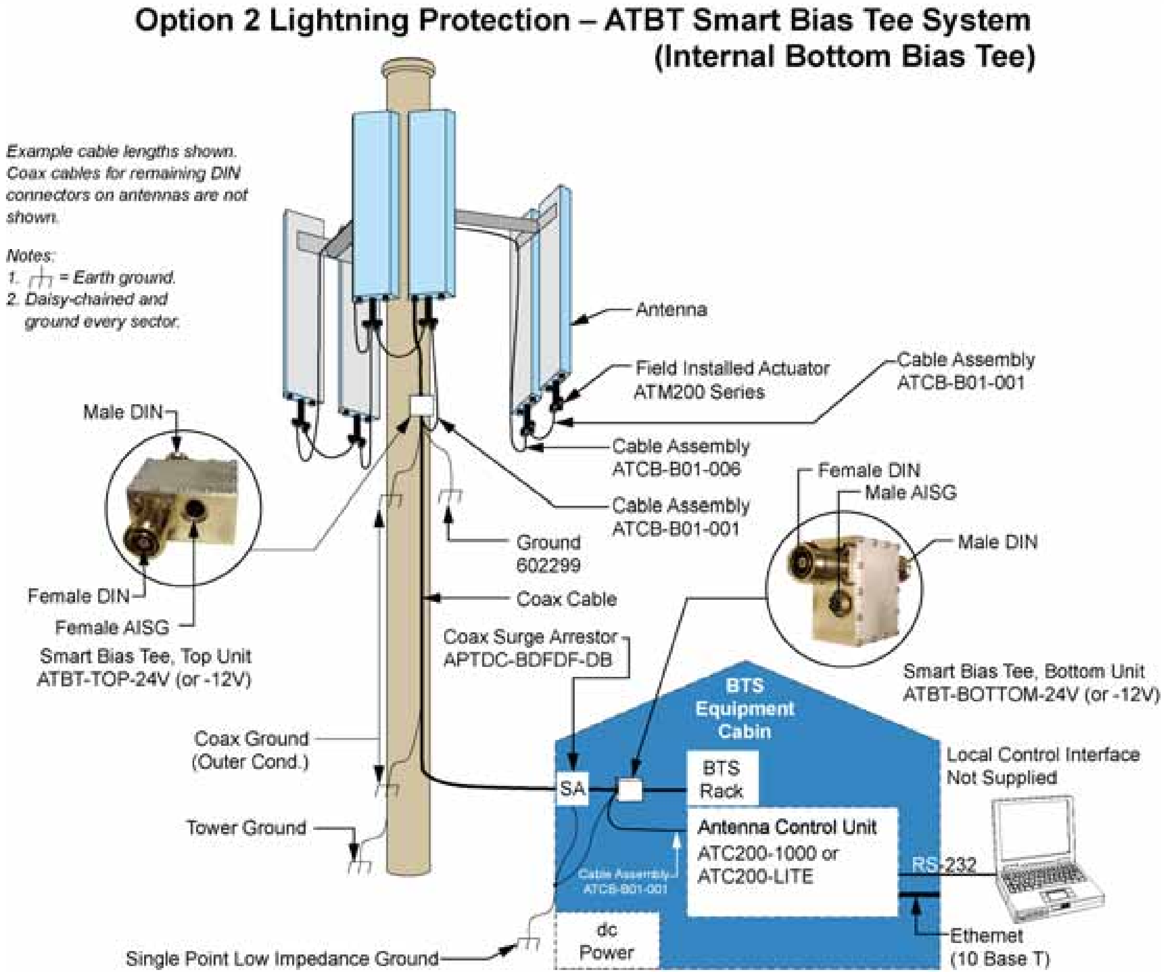

Figure 8. Antenna with RET/Smart Bias Tee (Inside BTS), Medium Protection Level.

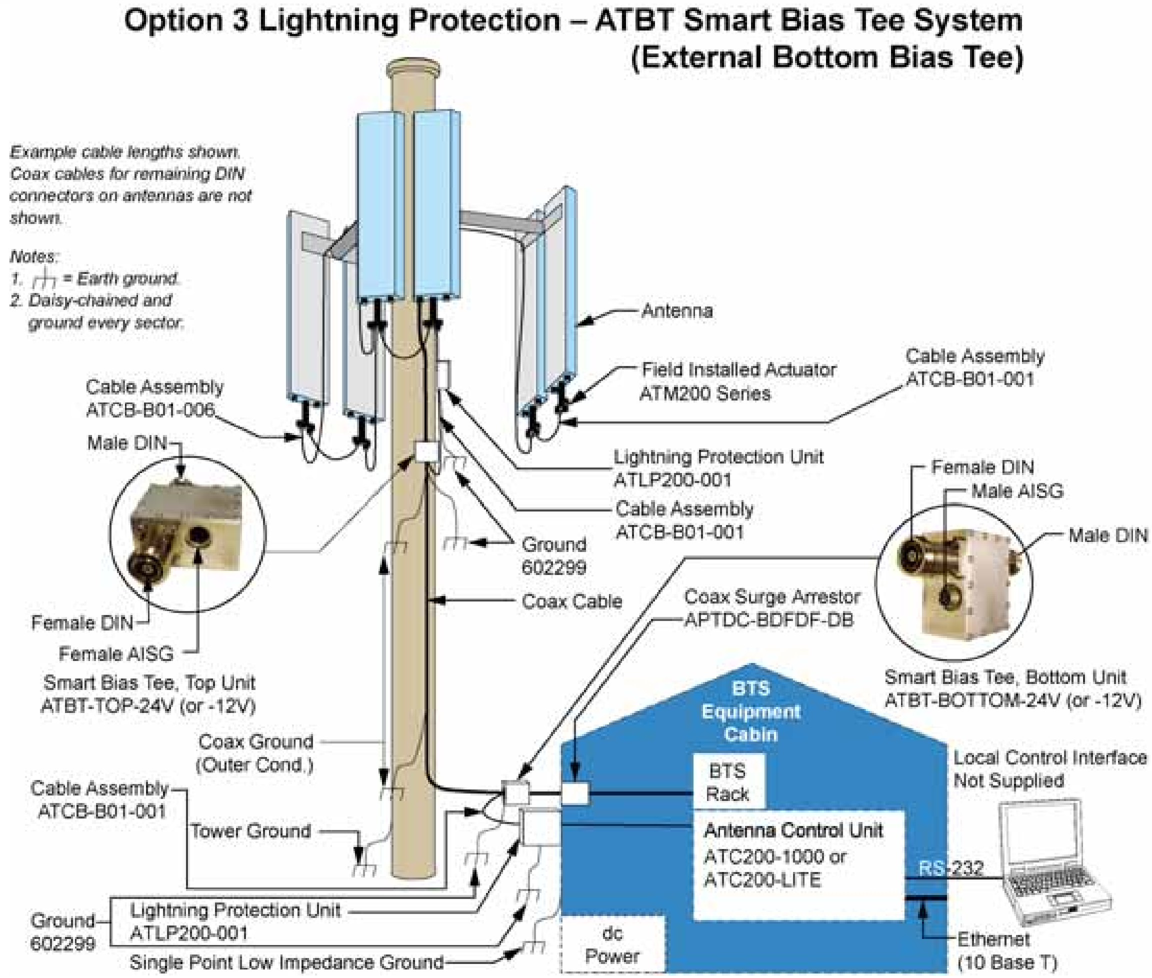

Figure 9. Antenna with RET/Smart Bias Tee (Outside BTS), High Protection Level.

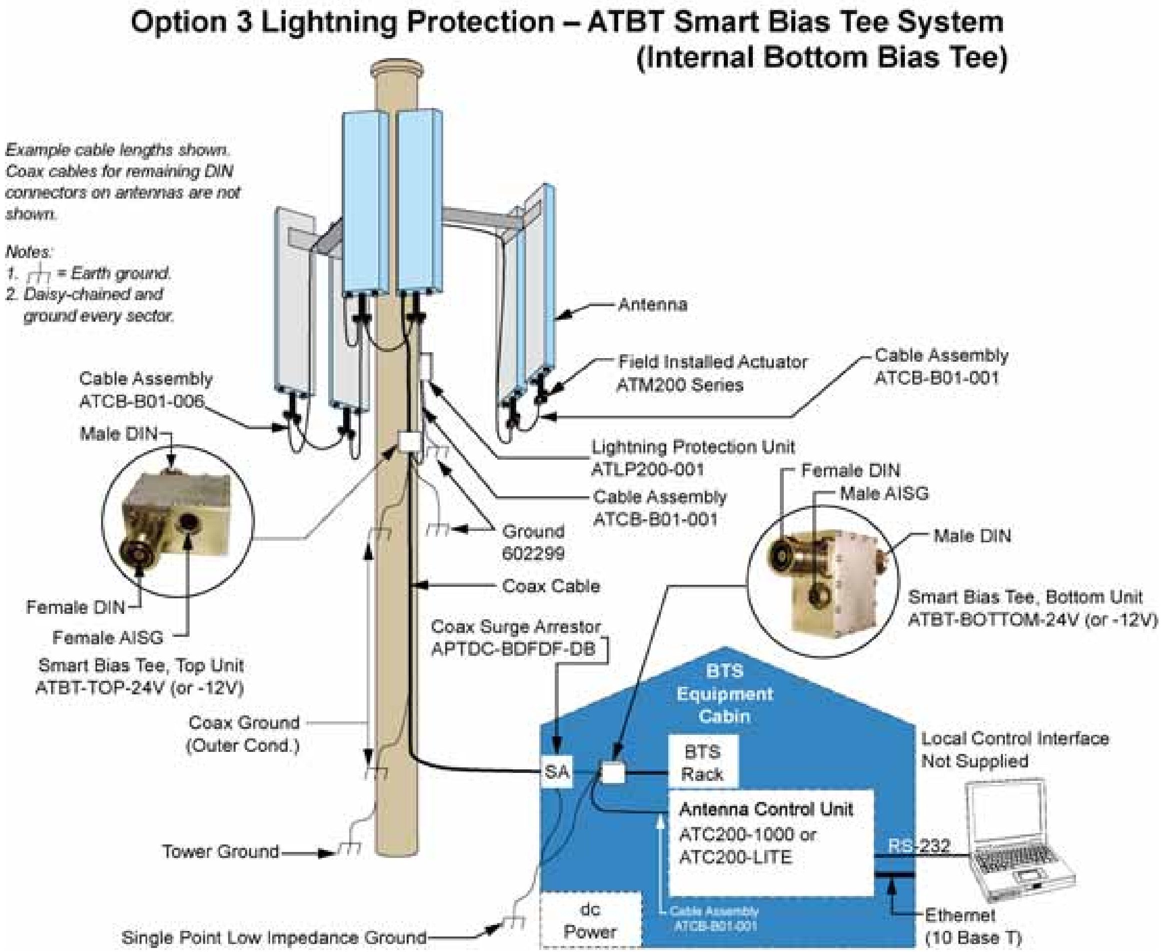

Figure 10. Antenna with RET/Smart Bias Tee (Inside BTS), High Protection Level.