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DESIGNS FOR SURGE IMMUNITY IN CRITICAL ELECTRONIC FACILITIES

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ABSTRACT

The Federal Aviation Administration is charged with maintaining a wide range of electronic facilities. These facilities range from pole mounted marker beacons, used as portions of an instrument landing system to Air Route Traffic Control Centers, responsible for thousands of cubic miles of air space. Because of the positioning and physical requirements of these facilities they are frequently subject to lightning related surges and transients as well as direct strikes. In recent years, FAA has embarked on a program replacing older tube type electronic equipment with newer solid state equipment. This replacement program has dramatically increased the susceptibility of FAA's facilities to lightning related damages.

This paper presents the author's proposal of techniques which may be employed to lessen the susceptibility of new FAA electronic facility designs to failures resulting from these causes. The general concept espoused is one of a consistent system approach employing both perimeter and internal protection. It compares the technique presently employed to reduce electronic noise with other techniques which reduce noise while lowering susceptibility to lightning related damage. It is anticipated that these techniques will be employed in the design of an ATCT in a high isokeraunic area. This facility would be subjected to rigorous monitoring over a multi-year period to provide quantitative data hopefully supporting the advantages of this design.

INTRODUCTION

Threat levels within FAA Southern Region facilities are characterized by a relatively low incidence of locally generated power line switching transients, unlike many industrial facilities. Typically the power line transients experienced at these facilities are from lightning generated surges, either locally or to the power distribution grid. Switching transients generated by the local power utility; or switching transients from industrial neighbors are far fewer and less likely to inflict damage on the facility. Lightning generated surges have been identified as the cause of the majority of the power line related surges which resulted in equipment failures. Direct strikes to FAA facilities are quite common and have been recorded on video tape on several occasions. FAA facilities on airports are interconnected with a web of signal, control and data cable which are also susceptible to lightning related transients.

Since the loss of FAA facilities may significantly impact the safety of the flying public, a stringent, rational as well as cost effective, approach to protection is warranted. The specious argument that protection should be implemented regardless of cost is totally unrealistic. Maintenance costs; facility and equipment purchase, and installation; and lightning protection all impact system reliability and thus flying safety while vying for the same budgetary dollar.

KEYS TO PROPER DESIGN

The scientist or engineer confined in a laboratory or office environment will find it difficult to identify all possible situations extant within the field environment. The complexities associated with the protection of a specific facility are extensive. Isokeraunic levels, thunderstorm strength, soil type, distribution system characteristics, relative and absolute elevation, soil moisture and composition, and equipment susceptibility levels are among the principal considerations. A rational approach to specific site design must examine these parameters and assign importance to each variable. This awareness of the impact of the environment is the first key to proper design.

Education is the second key to proper design. It is not possible to properly incorporate a given element of protection within a system of protection if the purpose and operation of that element is not understood. The impact of protective elements must be evaluated both during their normal operation and in a failure mode. A device connected in series with the power line which fails open is every bit as dangerous if not more dangerous than a surge which damages a component within the facility.

Regardless of the pains taken in designing an effective lightning protection system, all efforts are useless if the technicians charged with maintaining the system are unaware of the techniques employed.

Education is an ongoing process. Engineers charged with generating specific facility designs must have available support from engineers specializing in the application of lightning protection, grounding, bonding and shielding. For this reason, the educational process must flow in two directions. From the project engineer to the specialist engineer must flow information on the physical environment, regulatory environment, and constraints of purpose. From the specialist engineer to the project engineer must flow information on design goals, design techniques, device utilization and solutions to specific design problems. The accuracy of the data flowing in each direction will have a direct bearing on some elements of the data flowing in the opposite direction.

The third key to a proper design is a consistent review process. All facility designs, regardless of how simple, should be passed to the specialist engineer for review of the adequacy of design. Additionally, the review of these facility plans by field personnel prior to the letting of contracts will frequently prevent costly mistakes. Another source of loss of effectiveness is the failure to properly monitor the construction of the facility.

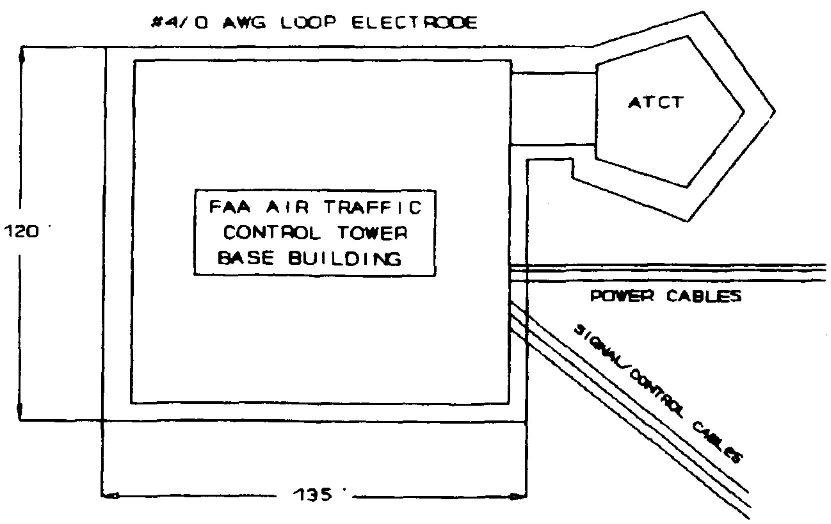

Figure 1
Standard FAA Protection

LIGHTNING PROTECTION

PRESENT FAA TECHNIQUES

FAA utilizes a system of lightning, surge, and transient protection based on the concept of creating an envelope of protection around the perimeter of the facility. This concept is mandated for all new construction or major modification by FAA-STD-019. This concept of protection is still valid but the lower threshold of susceptibility which is becoming apparent in recent procurements is such that improvements should be made.

The present system begins with the incorporation of integral, structural lightning protection. This protection is established to comply with NFPA-78, the Lightning Protection Code. The FAA system is designed to meet or exceed this code in all aspects. The system incorporates air terminals (lightning rods) which provide a zone of protection based on a 150' radius arc.

A loop electrode constructed of #4/0 AWG bare copper cable is buried 2 ft deep around the facility approximately 2 to 4 feet outside of the building foundation (or drip line). The typical grounding systems utilizes 10' by 3/4" copper clad ground rods spaced 20 feet apart around the counterpoise. These ground rods (earth electrodes) are exothermically welded to the 4/0 loop. All conductive paths entering the facility are bonded to this loop.

All power, control, or signal lines which penetrate the structural envelope should be equipped with surge/transient protection. This protection may include silicon avalanche suppressors (SAS), metal oxide varistors (MOV), or gas discharge devices. Carbon block type arresters are found in some telco equipment but are not commonly installed by the FAA. These devices are frequently incorporated into hybrid protection circuits installed at signal demarcs. Crowbar portions of these hybrid circuits are typically bonded directly to the external loop electrode. The clamp element is bonded to the internal multipoint grounding system.

The internal facility grounding system consists of three interconnecting grounds. The NEC required safety ground is incorporated as required for code compliance. All non-current carrying elements of the premises equipment are bonded to the grounding conductor. A second multipoint ground system is established which connects to the loop electrode with a 500 kcmil cable terminated at the main electronic ground plate. This plate serves as an interconnection point with the third, single-point, grounding system.

The multipoint grounding system utilizes building steel, where available and incorporates items such as ducts, cable trays, and conduits to create a grid of conductors. Where building steel is unavailable, 2000cmil/foot cables are utilized to interconnect the plates in this system. All racks and chassis are connected to this system.

The single-point ground system utilizes isolated plates and dedicated 500cmil/foot cables constructed in a star or tree pattern to ensure a single path to the main electronic ground plate. This system is designed to eliminate the system noise caused by loop currents.

PROTECTION FOR THE FUTURE

It began to become apparent in the late 1980's that the present FAA method of grounding was insufficient to provide the protection required for increasingly sophisticated facilities. A rethinking of the basic techniques was required which drew on numerous documents including FIPS PUB-94. A significant consideration for a new design was the ability to retrofit it to existing facilities and to establish it in facilities without significant amounts of building steel.

An additional problem appeared to result from the use of the single point ground system to minimize system noise. Constituent elements of systems which were directly connected to landlines were being protected while elements which were deeper in the system were receiving lightning related damage. It appeared that the poor bonding due to high frequency impedance inherent in a cable grounding system was allowing large voltage differentials to form between the elements. It was also apparent that a single compromise of a single point system resulted in a multipoint system with a single loop. This single loop system was found to be the noisiest possible ground.

New FAA air traffic control tower (ATCT) designs are on the drawing board. These new designs have tower shafts 300' tall. The direct strike risk associated with these towers mandates that we must assume that they will be struck on a regular basis when located in areas of even moderate isokeraunic activity. Protection for the electronics equipment located within these structures must be of a nature to prevent damage from this type of a strike.

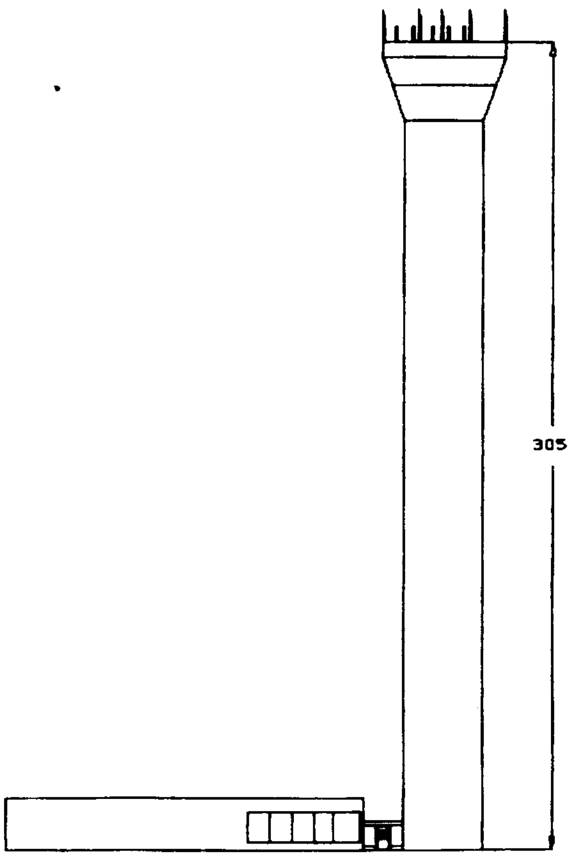

Figure 2
300' ATCT Design

In essence, these ATCTs incorporate two separate facilities within a single structure. These facilities are located over 300' apart. The first of these facilities is the terminal radar control and it's associated electronics located in the base building. The other facility is the ATCT cab and it's associated electronics located at or near the top of the tower shaft. The fact that this separation is primarily vertical enhances the voltage differential which is likely to be imposed upon them. Typically the tower shaft is constructed of precast, interlocking concrete modules. This construction technique reduces the vertical metallic elements to such items as metal staircases, cable trays, conduits and piping. External down conductors are utilized for the structural lightning protection.

PROTECTING THE TOWER TOP EQUIPMENT

Good design technique, for the reduction of electrical noise, locates signal and control wiring as far as possible from electrical wiring within the tower shaft. The utilization of fiber optic cabling between these facilities will minimize the threat of transients and noise coupled through the signal and control cabling. The power system is left as the single greatest threat other than a direct strike to the equipment located at the top of the tower shaft.

The first element of protection for the tower top facility is to establish a grounding grid or near equipotential plane for each level. These levels are interconnected with solid backed cable trays. These cable trays are supplemented with copper cabling to ensure the lowest possible impedance between these levels. These grids are connected to earth with a 500kcmil cable. The impedance of this cable is such that it cannot prevent differences in potential between the 2 facilities. The nature of this protection system is such that we recognize this effect but protect in a manner so as to render it inconsequential.

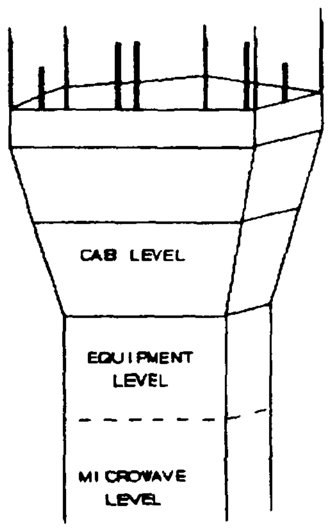

Figure 3
Tower Levels

The electrical power feed is brought into a service entrance at the microwave level. A secondary surge arrester is provided at this point. The grounded conductor (neutral) is bonded to the grounding electrode conductor and to the grounding conductor at this point. The normal mode surge arrester is connected between the phase conductors and the grounded conductor. The power ground and the grounding grid are interconnected at the microwave level through a main ground plate. The main ground plate functions as an interconnection point between the grounding grid and a single point ground system, if one is required[1]. The power feed for the levels is provided through a UPS system with critical power centers on each level. This minimizes stress between the power feed and signal and control elements.

Emergency communication equipment located within the tower cab is connected directly to antennas mounted on the tower roof. The coaxial cabling for these emergency transceivers is

[1]. Some equipment manufacturers mandate that an isolated ground be established for their equipment.

brought from the roof, where the shield is bonded to the structural lightning protection system, to the microwave level. At this point it is connected through a bulkhead plate utilizing a gas type surge protection device. The bulkhead plate is connected to the grounding grid on the microwave level. By connecting the bulkhead plate on the microwave level we minimize the differential between levels due to current flow from this source.

The utilization of fiber optic cabling between the tower top equipment and the base building equipment obviates the need for transient protection for the signal and control wiring. If there is a metal sheath on the fiber optic cable for physical protection this is bonded to the grounding grid at the microwave level.

PROTECTING THE BASE BUILDING EQUIPMENT

Many of the techniques utilized in protecting the tower top environment are applied in the base building. The first element is the establishment of a grounding grid or near equipotential plane for all equipment areas. The base building electronics are typically located on a single level. A raised floor extending under equipment room and the operational area is equipped with a grounding grid bonded to a conductive, rigid or bolted stringer, raised flooring system. The floor system and grid are interconnected at every other stanchion. This floor is bonded as frequently as possible to the building steel if available or alternatively to the loop electrode with 500 kcmil cable at a minimum of four points. The building steel is bonded to the loop electrode at alternate columns with #2/0 AWG bare copper cabling.

The electrical power feed is brought into a service entrance located in an emergency engine generator and power distribution room. A secondary surge arrester is provided at this point. The grounded conductor (neutral) is bonded to the grounding electrode conductor at this point and is in turn bonded to the grounding conductor. The normal mode surge arrester is connected between the phase conductors and the grounded conductor. The power feed for the levels is provided through a UPS system with a critical power center, connected as a separately derived source, in the equipment room.

A single point of entry for signal, control, and power cabling is utilized to minimize differentials at the point where the cables enter the raised floor area. Fiber optic cabling is utilized to the maximum extent possible for the signal and control cabling. These fiber optics are not expected to be all inclusive, however. Primary transient protection for these cables is provided at the building entrance with gas discharge and MOV devices connected to the loop counterpoise. Secondary protection with silicon avalanche suppressors is provided at the entrance to the raised floor area. Protection at the equipment is also required to be included on equipment manufactured to FAA specifications. The near equipotential plane functions as a means of minimizing the differentials due to the protective devices firing.

Cable entrances to the facility are through rigid metal (ferrous) conduit. This conduit extends 10 feet beyond the loop electrode and is bonded to it. Cable armor is also bonded out to the loop electrode.

Emergency communication equipment located within the operational area is connected directly to antennas mounted on the tower roof. The coaxial cabling for these emergency transceivers is brought from the roof, where the shield is bonded to the structural lightning protection system, to the base building level. At this point it is connected through a bulkhead plate utilizing a gas type surge protection device. The bulkhead plate is directly connected to the loop conductor with a #2/0 AWG copper cable.

SUMMARY

The present FAA concept of an envelope of protection is valid but it is necessary to carry the process a step further. Widely separate areas within a single structure must each have their own envelope of protection. The areas so protected must have a grounding system which minimizes the differentials within the envelope. All cabling entering the envelope must be closely referenced to this grounding system.

Even the best design can be compromised by poorly trained installers or technicians responsible for maintaining the system. The training of these people is every bit as critical as the proper design for protection.

The best general concept will usually fail to include in consideration at least one weak point. Lightning will ultimately find this point and cause damage within the facility. At this point the engineer must perform an in depth analysis to determine the weak point and protect it. When protecting this weak point it is important to consider the affect that this new protection will have on the overall system so as not to just move the problem.