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Lightning Protection of Wayside Train Control Systems

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Summary

Simulated lightning tests have validated technology and techniques that should protect safety-critical wayside train control systems from even the most severe electrical surges. The design concepts and recommendations to provide such protection were developed by a recent Transportation Technology Center, Inc. (TTCI) study.

The study was conducted under the Association of American Railroads' (AAR) Strategic Signal Research Initiative program with its primary objective to provide information and technical data to railroad officers on state-of-the-art surge protection procedures and devices. The study included a review of surge protection practices followed by railroads and other industries susceptible to lightning strikes on critical equipment. Aircraft industry practices, which use the metallic skin of the fuselage to form an electromagnetic shield (or Faraday shield) around flight-critical electronics, were found to be particularly relevant.

Existing metal wayside signal housings provide a Faraday shield around safety-critical electronics. However, wire and cable penetrations provide a means whereby interfering surges can be transported into interior spaces compromising the effectiveness of the Faraday shield. Accordingly, a prototype signal house was designed and constructed using a surge protection entrance panel based on the Faraday shield methodology. Subsequent validation tests at Lightning Technologies, Inc. confirmed that the Faraday shield panel was highly effective in mitigating surge effects within the prototype metal house, reducing both surge amplitude and duration when compared to existing techniques. The cost to implement this new technology will not significantly increase installation costs if integrated at the time of housing manufacture.

To facilitate railroad implementation of the principles developed during the study, the AAR Signal Research Technical Advisory Group mandated that the final report also include draft language for design recommendations to be considered for use in the American Railway Engineering and Maintenance of Way Association Signal Manual of Recommended Practice.

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Suggested Distribution:
- ❑ Maintenance of Way
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Work performed by TTCI Transportation Technology Center, Inc.
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INTRODUCTION AND CONCLUSIONS

Solid-state wayside signal and train control equipment should not be damaged by even the most severe electrical surges, including nearby lightning strikes, if installed and protected in accordance with the design concepts and recommendations developed in a recent TTCI study. Train delays, service disruptions, equipment replacement costs, and employee overtime that can result from such damage also could be significantly reduced. The cost to implement these concepts and recommendations will not increase installation costs if integrated at the time of signal housing manufacture.

The AAR Signal Research Technical Advisory Group (TAG) identified signal failures caused by lightning and power surges as a significant cause for train delays. The TAG questioned the adequacy of surge protection provided by current standards, practices and equipment design. As a result, this study was requested by the TAG and endorsed by the AAR Engineering Research Committee to determine and categorize the specific causes of this surge damage and develop cost-effective means of reducing or preventing it.

Prior to the start of this study, CSXT had also identified surge damage to electronic signal equipment as a significant cause of train delays. Consequently, the company engaged Electro-Magnetic Associates of Denver to conduct a comprehensive study of existing signal installations and practices and develop more effective alternatives. CSXT agreed to share the findings, and many of the valuable insights and concepts developed in the work for CSXT were incorporated in the TTCI study.

A review of current practices and railroad experiences indicated that currently available signal surge protection devices themselves appeared adequate.The TTCI study was directed more toward improving the effective application of surge protection devices than to investigating the devices themselves and included the following:

- Assessments of electronic surge protection schemes utilized in the aircraft industry practices were found to be particularly relevant, as aircraft sustain repeated lightning strikes and equipment reliability is essential. In the case of an aircraft, the skin of the fuselage forms an effective Faraday shield which effectively isolates and shields aircraft electronics from environmental interference.
- Existing wayside metal signal housings also provide an effective Faraday shield. However, aerial and buried conductors must penetrate the housing, providing a means whereby lightning surges can be transported into interior spaces. The study identified, tested, and evaluated techniques to shield these conductors and thus maintain the effectiveness of the Faraday shield housing.

PROTOTYPE SIGNAL HOUSE

A prototype signal house was designed and constructed using Faraday shield methodology. Surge protection entrance panels were developed using traditional signal industry termination hardware and spacing so that existing primary signal line arresters, available from several suppliers, could be installed. By this means, the cost of the new Faraday shield panels should not exceed that of traditional wood panels for new installations.

As high surge currents in ground conductors within the signal house have been shown to be a source of induced surge voltage in other signal circuits, all ground connections from arresters were made directly to the metal skin of the house. The Faraday shield concept was also extended to the AC power wiring by placing all of the interior wiring in metallic conduit and electrical boxes.

To determine the effectiveness of this concept and design, a typical electronic grade crossing control system was installed in the prototype house and connected to an external simulated track, with operational flashing lights and gate mechanisms. Electrical surges representative of those associated with nearby lightning strikes were impressed sequentially on all external circuits, including track, flasher, gate, and AC power.

To establish a "baseline" for the Faraday shield test results, a wood surge protection entrance panel was constructed and installed in the signal house. It utilized construction techniques typical of those still widely used by railroads today. The same arresters were used in both applications. Internal house wiring and electronic equipment were also the same. The baseline signal house underwent the same surge testing as the Faraday shield concept house.

SURGE TEST RESULTS

Surge testing was conducted at Lightning Technologies, Inc. (LTI) in Pittsfield, Massachusetts. This laboratory has surge generators capable of simulating actual lightning strikes, as well as instrumentation to measure and record electrical surges with nanosecond timing. The tests used IEEE standard procedures and waveforms at surge levels representative of a typical railroad wayside environment. Critically designed test procedures utilizing high-speed oscilloscopes and calibrated meters were used to accurately determine surge levels and waveforms.

The Faraday shield design developed in the TTCI project was found to be highly effective in mitigating surge effects within the prototype house and provided adequate equipment protection for even severe simulated nearby lightning strikes.

Both the amplitude and duration of surges measured at the equipment terminals were significantly lower for the Faraday shield design than for the base case. Exhibit 1 shows oscillograph waveforms comparing the Faraday shield design to the base case, measured at the track circuit input terminals of the grade crossing warning equipment when surges were impressed upon the external track circuit wires. In both cases, the impressed surge was an IEEE standard 8 X 20, 20 kA waveform (8 µsec rise time, 20 µsec duration, 20,000 Amps peak) which would be typical for a nearby lightning strike.

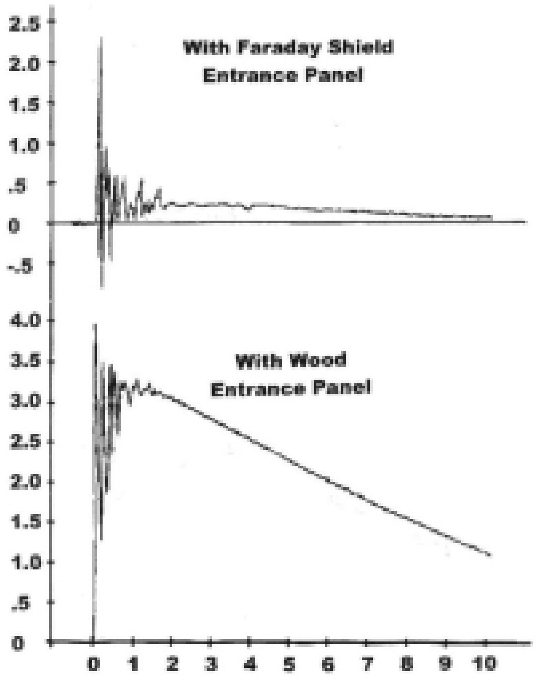

Exhibit 1. Oscillograph Waveforms Comparing Faraday Shield Design to the Base Case

Panel Type	VPeak	Surge Duration
Faraday	2.45 kV	<1 µsec
Wood w/ 34" Ground Lead	5 kV	>10 µsec
Wood w/ 17" Ground Lead	4.00 kV	>10 µsec
Wood w/ Aluminum Buss	3.40 kV	>10 µsec

Exhibit 2. Surge Peak Voltages and Duration for Alternative Entrance Panels

There was no effect, either short term or long term, on the operation of the electronic equipment in the signal house for any surge level in the Faraday shield design signal house throughout the surge testing. More than 200 surges of various levels were impressed on various circuits in this house. However, equipment surge damage did occur with the wood entrance panel with an internal 34-inch ground wire from the arresters. This was then reduced to 17 inches and no further damage occurred.

All surge amplitudes at the equipment terminals and in the electric field “sense” wires during the testing were significantly higher for the wood panel with a 17-inch ground than the Faraday shield design panel. It is important to note that virtually all existing signal houses with wood panels have internal ground wires well in excess of 17 inches and most are longer than 34 inches. Exhibit 2 shows the results of the signal I/O surge tests with 8 x 20 µ, 20 kA surge injected into the track lead. Note that the surge duration was increased by a factor of more than 10 for all wood panel tests, as compared with equivalent Faraday shield panel tests.

When signal line surge protectors from different manufacturers were substituted in the Faraday shield entrance panel, no significant difference in surge amplitude or duration was noted. In all cases the electronic equipment was adequately protected. Several solid-state surge protectors that have recently been marketed for AC power lines were sequentially installed and tested with similar surges. While some performed more effectively than others, all provided adequate equipment protection.

Methods of grounding the signal house externally, as well as adjacent signal masts, were also investigated. While the external grounding scheme is primarily required for personnel protection, it can also reduce electrical "noise" pickup and surge stress on the control system.

Another important mitigation technique, validated during the tests at LTI, is that all circuits entering or leaving the house must be protected with arresters at the surge entrance panel or electrical service box, regardless of type of circuit or destination. If an unprotected circuit is allowed to enter the house, the Faraday shield concept is violated.

Railroads develop detailed circuit plans for safety-critical train control systems. Nevertheless, there is still considerable leeway given to the individual routing of wires and equipment layout within the signal house. One of the study's goals was to configure the surge protection entrance panel to force proper installation procedures in critical areas. Thus, the individual doing the interior wiring need only follow and check the circuit plans — configuring for effective surge protection would be assured by the basic house design.

CONCLUSION

Signal and train control equipment must be constructed to specified surge withstand (tolerance) levels. These levels are described in the AREMA Signal Manual of Recommended Practice. This, together with the best of current railroad techniques, use of a Faraday shield surge protection entrance panel, fully enclosed AC power wiring, and currently used surge protection devices, can result in a highly surge-resistant control system.

The improvement in equipment protection achieved in the new design over traditional signal house construction was very significant. It was concluded from the testing that solid-state train control equipment should not be damaged by even the most severe electrical surges, including nearby lightning strikes, if installed and protected in accordance with the design concepts and recommendations described in the TTCI study. Train delays, equipment replacement costs and employee overtime could be significantly reduced as well.

To facilitate railroad implementation of the principles developed during the study, the Signal Research TAG mandated that the study's final report also include draft language for design recommendations. This draft language was provided to Committee 38 as information for potential inclusion within the AREMA Signal Manual of Recommended Practice.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.