Abstract

Railroads running through mountainous terrain are subject to hazards from rockfalls, landslides, avalanches and washouts. Railroads currently deal with some of these hazards by using slide fences. Existing slide fence technology consists of a “fence” constructed with posts and parallel, horizontal wires. Fences require frequent repairs, and reconstruction, are prone to false activations, and are often located in hazardous work areas. Trains are often required to operate at restricted speed until fences are repaired. Fence construction is expensive and can be as much as $200/foot of fence. In 1997, Canadian Pacific Railway, Canadian National Railway and SAIC formed a partnership to develop a system that would address the deficiencies with the existing slide fence technology by initiating a three phase development project. This paper outlines the results of Phase One of the development project. Phase Two of the project is currently proceeding and will be completed during the summer of 1999.

The RailAlert Electromagnetic Field Disturbance Rockfall Detection system senses very small changes in the electromagnetic field set up by the system. These changes are caused by rockfalls, landslides and washouts, as well as by “noise” factors such as rail traffic, animals and changing environmental conditions. The principle of this topology is that an object coming in close proximity to this cable will modify the electrical properties of the cable and result in a change in phase of the signal propagating down the line. The cable topology used is a custom design consisting of two balanced 18 AWG conductors spaced approximately 5 cm apart. Two prototypes were installed and tested during in 1998. Extensive field testing of the technology and subsystems has provided encouraging results. Test systems were able to reliably detect a simulated foot-cubed target rock. Testing of Beta systems will continue during 1999.
1.0 Introduction – Existing Technology

Railroads running through mountainous terrain are subject to hazards from rockfalls, landslides, avalanches and washouts. Railroads currently deal with the threat of rockfalls, landslides and avalanches by using slide fences. The existing slide fence technology consists of a “fence” constructed with posts and parallel, horizontal wires. The wires are spaced on the posts every 6” to 18” such that falling material such as rocks break the wires or pull open a spring-loaded contact causing the signaling system to restrict train speeds through the slide zone until the fence can be reset. Thus detection of a falling object damages the slide fence which must be repaired before it can detect a future event.

1.1 Problems with Existing Technology

1. Fences need frequent repairs, and reconstruction. Fences are damaged as a result of their operation. They must also be taken down and reconstructed whenever rock scaling is required in the area.

2. Fences are prone to false activations that require repair. Due to location, this requires that maintainers work in hazardous areas. While the fence is inoperative, trains are required to operate at restricted speed, resulting in delays to rail traffic.

3. Initial fence construction is very labor intensive and anchoring posts in rock is expensive. Fence construction costs can be as much as $200/foot.

A basic evaluation of an improved technology for rockfall detection system was performed in a partnership between Transport Canada and Canadian National in 1990-1992. This research project identified a number of potential problems that would need to be addressed in order for the technology to meet rail industry requirements. In 1997, Canadian Pacific Railway, Canadian National Railway and SAIC, along with Microlynx Systems, formed a partnership to develop a system that would address the deficiencies with the existing systems. Transport Canada has continued the support for this technology development. The Field Disturbance Detection System is the result of this joint effort.

Figure 1. Typical Existing Slide Fence
1.2 Project Overview

A three phase development project was initiated, as follows:

1. Development of an Alpha Test system to:
   • Gather field and laboratory test data.
   • Confirm that the technology application is feasible.
   • Test and define performance and configuration of subsystems for detailed testing of the proposed system.

2. Install fully operational Beta/Pilot Systems to:
   • Confirm system design.
   • Test performance against the prescribed performance requirements.
   • Operate in parallel with existing slide-fence technology.

3. Install functional standalone systems

This paper outlines the results of Phase One of the development project. Phase Two of the project is currently proceeding and will be completed during the summer of 1999.

1.3 Potential Benefits and Functional Requirements

The potential benefits of an improved solution to the problem presented by rockfall hazards are:

• More economical initial cost.
• Reduced repair and reconstruction costs.
• Reduced track time required to physically remove accumulated debris by avoiding costs associated with slide fence removal and reconstruction.
• Increased safety for maintenance personnel.

The functional requirements for a solution based on a new technology are:

• The system must be able to detect objects that are hazardous to train movements. The system should function as effectively as existing slide fences without interfering with rail operations.
• The system must be designed to minimize the probability of rocks, exceeding the specified size, from entering the detection zone without being detected. The occurrence of false (non-hazardous) activations must be minimized.
• The system should reduce the time spent in hazardous areas repairing the system, with all repairs at grade level.
• The system should have a reduced cost per foot installed so that more areas can be sensed. Installation should not require extensive site preparation.
• The system must continue to function after a minor event, allowing for remote resetting to minimize train delays. The first train can proceed into the detection zone prepared to stop for an obstruction. If the alarm was caused by a non-obstructive event, the system can be reset and subsequent trains can proceed at track speed.
2.0  RailAlert – System and Technology Overview

The RailAlert Electromagnetic Field Disturbance Rockfall Detection system consists of the following key components and subsystems:

- System Processor and RF Transceiver
- Transmit and receive cables
- Protective carrier for cables.

2.1 System Processor

The System Processor is a microprocessor-based unit that automatically monitors and controls the output from the RF Transceiver board. The processor unit provides global processing features for all sensor zones to minimize environmental nuisance alarms. The processor unit also allows remote interrogation of the system in order to reset alarms, adjust parameters, interrogate system operation, download new software, and upload stored data.

2.2 RF Transceiver

The RF Transceiver board controls the electromagnetic field around the sensor cables. If the field is disturbed, the RF Transceiver board will receive the information and pass the data to the System Processor for analysis. If warranted, the System Processor will declare an alarm and activate a relay output. The RF Transceiver board will be connected to the sensor cables and provide detection for up to a 200 m zone.

2.3 Principle of Operation

The RailAlert rockfall detection system senses very small changes in the electromagnetic field set up by the system. These changes are caused by rockfalls, landslides and washouts, as well as by “noise” factors such as rail traffic, animals and changing environmental conditions. The system works by sending a continuous series of waves (frequency) down a transmission medium (cable) and detecting any changes (phase shift) in the speed of transmission by comparing the time of the transmitted signal to the arrival time of the received signal. The principal at work is the same as the bending of light when it goes from air to water. The density of water is different (greater) than the density (dielectric coefficient) of air so that the wave bends (slows) as it makes the transition from air to water (most noticeable when viewed at an angle in the air-water analogy).

The RailAlert Electromagnetic Field Disturbance Detection system seeks to maximize the sensing of changes in the environment (rocks/chunks of snow) in the vicinity of the transmission medium by using a conducting path that is effected by nearby changes. However, this must be done in a controlled manner to minimize all the random external (noise) effects that cause undesired effects. So the system must transmit along a medium that allows interaction with the surrounding environment yet maintains a controlled environment so that changes can be sensed.
The field is established by transmitting a radio frequency (RF) signal on a special transmission cable that is sensitive to its environment. This same RF signal, but now modified by its environment, is received by the RailAlert system. There it is filtered to remove unwanted interference, amplified, and compared to a constant reference frequency generated internally. Any changes in the field will result in changes to this comparison signal. The comparison signal is digitally sampled and sent to a processor, which performs mathematical functions to provide smoothing, eliminate drift conditions, etc. A sudden change in comparison signal indicates that an event has occurred.

2.4 Cable, Cable Topology and Cable Protection

The cable topology is a custom design consisting of two balanced 18 AWG conductors spaced approximately 5 cm apart. The principle of this topology is that an object coming in close proximity to this cable will modify the electrical properties of the cable and result in a change in phase of the signal propagating down the line. This change in phase, if it is rapid enough, is detected by the system. The software filters out the slow changes caused by environmental effects like temperature variations and precipitation.

In order to protect the sensing cables and ensure consistent conductor spacing, a custom rugged neoprene extrusion was designed and manufactured. This extrusion was designed to optimize and maintain the spacing of the sensing conductors, maximize the conductor protection and minimize maintenance efforts. A cross-section of the neoprene cable carrier is shown in Figure 2.

![Figure 2. Cross-section of Cable Protective Carrier](C) AREMA (R) 2000

2.5 RailAlert System Configuration

The most basic system configuration consists of a Master Unit, which is the minimum configuration that can operate as a detection system. The basic Master Unit system can be expanded by the addition of Remote Units to handle larger or more complex installations. The operation of the Master Unit does not require communications to and from a Remote Unit. The building blocks of a typical Rail-Alert rockfall detection system are shown in Figure 3.
A Master Unit consists of a Master Processor, a Sensor Unit; additional cards as required for each installation, such as modems, Talkers, etc.; an enclosure; lightning protection; one Active Sensor cable per Remote Unit; and lead-in coax cable to access the active cable.

A Remote Unit consists of a Sensor Unit mounted in an enclosure, with lightning protection, lead-in cable and active cable, as well as Power & Communications cable.

The minimum system configuration consists of a Master Unit. This can be expanded through the addition of up to three Remote Units in each direction. Both the Master Unit and the Remote Unit can support either one or two Transceiver Cards. This allows great flexibility in the configuration of a particular system. For example, Figures 4 shows a typical minimum RailAlert configuration with a Master Unit with two Transceiver Cards installed, providing coverage in two directions. Figure 5 shows an example of an expanded system where a Master controls two Remotes located at one side of the detection area. Note that the Remote Unit #1 is configured with an expanded detection zone in order to provide enhanced detection capability at its location such as might be required for center-track and track-edge protection.
3.0 Alpha Testing and Test Results

3.1 Test Systems

Two prototype systems were installed and tested during 1998. These systems were used to gather field and laboratory test data; confirm that the technology application was feasible; and test and define performance and configuration of subsystems. In addition, these systems were used to develop the system processing algorithms. The two test sites were Golden, B.C. on the CPR mainline, and Lasha, B.C. on the CNR mainline. A diagram of the CN installation at Lasha near Lytton, BC. is shown in Figure 6. This phase of the project was completed in 1998.
Each Alpha Test system consisted of a case with a computer, which included two rockfall detection prototype boards. Each board was connected, through buried lead-in cable, to an active cable pair that was mounted between the rails. The CN Lasha installation used sturdy HDPE conduit to protect the sensing cable. Since CN uses concrete ties at this location, conduit was periodically attached to the ties using metal hooks that were anchored to the ballast. There were two active cable runs, one heading East and one heading West. Each run was originally approximately 200 meters long. In an attempt to improve sensitivity, the W run was cut during the testing process to approximately 123 meters. Photographs of the case and installation are shown in Figure 7.

Figure 7: Rockfall Detection Equipment (L) and cable (R) at CN Lasha

3.2 Preliminary Field Test Results

The test results were as follows:
- The field disturbance detection system is able to detect events on both wood and concrete ties. However, the effect of concrete ties appears to cause a reduction in error magnitude for a given event. However, concrete ties also appear to reduce the background noise, so that detection of events with concrete ties remains feasible.
- A number of options are possible to terminate the cables at the far end, including terminating the cables in 50 ohms, looping them back on each other, and leaving them open-circuit. The loop-back configuration was best able to detect a barrel at the outside of the rail.
- It does not appear feasible to compare the signal before and immediately after a train to provide some level of protection while the system resets itself after train passage. This is because the cable shifts due to vibrations caused by the moving train. Improved cable mounting techniques to reduce settling may help this situation.

The 1998 tests were an excellent source of data but also raises a number of concerns:
- The effect of reinforced-concrete ties on system sensitivity. There were differences in system performance between wood ties and concrete ties.
• Run-length limitations remain a possibility. Detailed sensitivity-vs.-position tests will be required for various run lengths.
• The various cable termination options (50 ohm load; loop-back or open-circuit) would require further tests to optimize.
• Cable performance, protection and long-term maintenance issues. These were addressed by additional field testing.

3.3 Cable Test Results
The conducting medium, the cable, is key to this project. Previous research efforts had used an expensive, graduated leaky coax cable. However, a successful Railroad application of the technology requires a cable that is compatible with the "Railroad Environment", that is:
  • The cable must be extremely rugged and preferably able to withstand being run over by tracked equipment
  • The cable must be reasonably easy to install.
  • The cable should be easy to repair, even during inclement, winter weather conditions.
  • The cable should be economical.

A number of issues related to the actual sensing cable technology were identified during the early Alpha field testing phase of the project. In light of these results and Railroad requirements, the coax cable had many deficiencies and considerable effort was spent investigating alternative cable arrangements and topologies. As result, an improved sensing cable topology was developed and tested. A configuration consisting of 5 cm parallel twin conductors was selected for the following reasons:
  • The sensing area around the cable was maximized and controlled.
  • The sensing area minimized uncontrolled external influences that might cause unnecessary activations, while minimizing noise and null effects.

The cable tests were performed at CP’s Alyth Yard. These tests were also used to fine-tune improved test procedures, and prove system operation prior to planning for the Beta system testing (which is occurring in 1999).

3.4 Cable Topology
The revised cable topology consists of two balanced conductors spaced approximately 5 cm apart as previously discussed. For the Alyth installation, 1” x 3” graded cedar planks were used that were notched with a saw blade to allow the conductors to be held in place by the notches. Figure 8, shown below provides a cross section.

![Figure 8: Cross-section of Alpha Cable Topology](Figure 8: Cross-section of Alpha Cable Topology)
The principle of this topology is that an object coming in close proximity to the sensing cables will modify the electrical properties of the cables and result in a change in phase of the signal propagating down the line. This change in phase, if it is rapid enough, is detected by the system. Slow changes are filtered out in software. For the Alyth test system, approximately 100' of active cable was used and mounted at the outside edge of the ties. One end was connected to the transmitter, the other end to the receiver.

3.5 Test Procedures

For the Alyth field tests, a stack of 12” x 12” marble tiles was used. These tiles have the same electromagnetic characteristics as actual rocks but allow accurate measurement of the performance. The tiles were held off the cable with a two sections of 2” x 4”. This spacing was used to ensure that the electrical effects alone were being observed, rather than mechanical (microphonic) effects, i.e. the tiles should never have touched the cable. A string was attached to the stack of tiles to allow it to be lowered or raised. To test the system, the stack was gently lowered until the 2” x 4” just rested on the tie, providing approximately a 1” spacing between the tiles and the cable. Then, every 10 seconds, the target was quickly raised away from the cable and moved to the next tie. This approach was used in order to minimize the possibility of detecting the mechanical effects. Test results are shown below in Figure 9.

![Figure 9: Cable Topology Test Results](image)

As can be seen, the error signal was, in general, cleanly detected by the system. The average background noise signal was measured to be approximately 0.25 on that scale, with a peak background over 10 minutes of 2.1. In other words, setting the detection threshold to say 5 would virtually assure that false triggers due to random noise would not occur. The detection amplitude should, in theory, be constant with distance along the cable. Variations in amplitude observed can be attributed to variations in distance between the tiles and the cable, the speed with which the tiles were removed, and the exact time of the event within the sampling range.
4.0 Test Conclusions

Extensive field testing of the technology and subsystems has provided some very encouraging results. The following preliminary conclusions can be drawn:

1. The target simulated a foot-cubed rock and provided a detectable signal almost all of the time. This is substantially smaller than the 18” x 18” x 18” target objective. A larger rock, especially including the electromechanical effects, should be detected with a high degree of certainty.

2. Based on the measured losses, it is expected that the active cable can be extended to over 100 m without difficulty.

3. Detection field range was small – several inches - but multiple low cost parallel runs of cables could be used to tailor the detection zone to meet specific site requirements while ensuring that the system detects rocks that are of a size that is hazardous to the operation of the train. This results in a system that is not prone to false activations caused by rocks falling a safe distance from the tracks. The system will also likely reject the presence of animals walking near, but not on, the tracks. A clearance diagram with possible detection zones is shown in Figure 10.

![SD90MAC Locomotive Clearance diagram](image-url)

**Figure 10:** SD90MAC Locomotive Clearance diagram