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Railway Rockfall Electromagnetic Field Disturbance Sensing System Development and Test Results

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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Un sommaire français se trouve avant la table des matières.

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16. Abstract

This report details the work done in Phase 1 and the initial stages of Phase 2 of the project originally titled *Guided Wave Radar Rockslide Detection Research Project*. The primary purpose of the project was to design and develop an electronic system for detecting rocks falling on railway tracks, a sensing system intended to augment or replace existing slide fences. Specifically, the goal was to develop an electronic system that, unlike current slide fences that rely on the loss of electrical continuity when a falling rock breaks a wire, would detect objects without damaging the sensing system. This would allow the system to be reset and quickly returned to operation after site inspection and obstruction clearance. This project is an extension of a previous Transport Canada project (see TC Publication TP 11445E*, Guided Radar Landslide Detection*), which produced promising results while identifying technological challenges to be addressed.

The result of this project is the Electromagnetic Field Disturbance (EMFD) rockfall detection system. This system works by transmitting a radio frequency (RF) signal on a special transmission cable that is sensitive to its environment. When the EMFD system receives an RF signal modified by its environment, the signal is filtered to remove unwanted interference, amplified, and compared to an internally generated constant reference frequency. Any changes in the field will result in changes to the received (comparison) signal. A sudden change in a received signal is taken to indicate that an event has occurred.

The EMFD system shows promise to increase railroad efficiency and safety. The sensing cable is relatively low-cost, easily repaired, quick to install and compatible with normal railway operations including snow removal. Problems with the processing software still need to be overcome and it is recommended that product development and testing continue (in conjunction with the electronics designer) until the EMFD system is fully functional.

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16. Résumé

Ce rapport présente les travaux réalisés au cours de la phase 1 et des premières étapes de la phase 2 du projet intitulé à l'origine *Détection de glissement rocheux par radar à ondes guidées*. Le but premier du projet était de concevoir et développer un système électronique de détection des chutes de roches sur des voies ferrées, destiné à s'ajouter aux clôtures de détection ou à les remplacer. Le projet visait plus particulièrement la mise au point d'un système électronique qui, contrairement aux clôtures actuelles, dont le signal est déclenché par la perte de continuité électrique associée à la rupture d'un câble, détecterait les objets sans subir de dommage. Il deviendrait ainsi possible de rapidement réamorcer et remettre en marche le système après avoir inspecté et désobstrué le site. Ce projet est le prolongement d'un autre projet de Transports Canada (voir la publication TP 11445E de TC*, Guided Radar Landslide Detection*), qui, malgré des résultats encourageants, mettait au jour divers obstacles techniques.

Le présent projet a donné le système de surveillance d'éboulement par capteur de perturbation de champ électromagnétique (EMFD, pour *Electromagnetic Field Disturbance*). Ce système est fondé sur l'émission d'un signal à haute fréquence dans un câble de transmission spécial, sensible au milieu ambiant. Lorsque le dispositif EMFD reçoit un signal à haute fréquence modifié par le milieu, il le filtre pour éliminer l'interférence indésirable, l'amplifie et le compare à un signal de référence interne à fréquence constante. Toute perturbation du champ électromagnétique modifie le signal reçu (aux fins de comparaison). Et toute modification soudaine du signal reçu est présumée signifier qu'un événement s'est produit.

Le dispositif EMFD laisse envisager un accroissement de l'efficacité et de la sûreté des voies ferrées. Le câble de détection est relativement peu coûteux, facile à réparer, rapide à installer et compatible avec les activités normales sur une voie ferrée, y compris le déneigement. Il reste toutefois des difficultés à surmonter du côté du logiciel, d'où la recommandation de poursuivre le développement et l'essai du produit (en association avec le concepteur de l'électronique) jusqu'à ce qu'il soit tout à fait fonctionnel.

17. Mots clés
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This project has been a joint effort between Canadian Pacific Railway and Canadian National Railway working with a proven railway equipment supplier – SAIC – and a commercial electronics research and development company – Microlynx Systems – to develop a rockfall and washout detection product based on electromagnetic perimeter sensing technology.

EXECUTIVE SUMMARY

The primary purpose of the Electromagnetic Field Disturbance (EMFD) Rockfall Detection Project was to design and develop an electronic system to detect rocks falling on railway tracks. Such a system should be compatible with railway operations and is intended to augment or replace existing slide fences.

Surface transportation systems running through mountainous terrain are subject to rockfall hazards. Railway companies currently deal with this threat by using slide fences: parallel wires strung about 8 in. apart on poles that are located on the uphill side of the track in the slide area. When a rock falls through the fence, it breaks a wire, and the loss of electrical continuity is detected. The disadvantage of this system is that detection of a rock requires damage to the sensor and subsequent repair work, often in a hazardous environment.

This project was an extension of a previous Transport Canada project. (TP 11445E, *Guided Radar Landslide Detection*), the results of which were promising. However, a number of technical challenges were identified.

The objective of the EMFD Rockfall Detection Project was to develop an electronic system that, unlike slide fences that rely on the loss of electrical continuity when a falling rock breaks a wire, would not depend upon system damage for detection to occur. What was required was a system that could be quickly reset and put back into operation after site inspection and obstruction clearance had been completed. The existing slide fences are difficult to repair and hinder rapid clearance of obstructions.

The result of this project has been the development of the EMFD rockfall detection system. This sensing system works by sending a continuous series of electromagnetic waves down a transmission medium (cable) that is configured in a loop between the transmitter and receiver. The velocity of propagation, or speed of transmission, of the waves is determined by the material close to the cable. Any changes in the velocity of propagation are determined by comparing the phase of the transmitted signal to the phase of the received signal. A rock landing near the cable will slow down the wave and result in a phase shift. A rapid phase shift indicates a possible obstruction on the track. The sensing cable is relatively low cost, easily repaired, quick to install and compatible with normal railway operations including snow removal.

A number of operational issues remain to be resolved. The test systems currently being evaluated show a relatively high rate of random triggering, and any final system will require that this false alarm rate be significantly reduced. The cable design itself also needs further work to make it more rugged.

SOMMAIRE

Le but premier du projet de surveillance des éboulements par capteur de perturbation de champ électromagnétique (EMFD, pour *Electromagnetic Field Disturbance*) était de concevoir et développer un système électronique pour détecter des chutes de roches sur des voies ferrées. Ce système devait être compatible avec les activités sur une voie ferrée et devait pouvoir s'ajouter aux clôtures existantes ou les remplacer.

Les véhicules de transport de surface qui circulent en zone montagneuse sont sujets au risque d'éboulement. Pour pallier cette menace, les compagnies ferroviaires mettent en place des clôtures spéciales, constituées de câbles électriques parallèles tendus à environ 8 pouces de distance entre des poteaux, situées en amont de la pente par rapport à la voie ferrée. Lorsqu'un bloc rocheux heurte la clôture en tombant, il brise un câble, ce qui déclenche un signal de perte de continuité électrique. L'inconvénient de ce système, c'est que la détection d'un éboulement passe par l'endommagement du capteur, qui doit ensuite être réparé et ce, dans un environnement souvent dangereux.

Ce projet était le prolongement d'un projet antérieur de Transports Canada (TP 11445E, *Guided Radar Landslide Detection*), qui avait donné des résultats encourageants, mais avait aussi mis au jour un certain nombre d'obstacles techniques.

L'objectif du projet de EMFD était de mettre au point un système électronique dont la fonction de détection ne serait pas tributaire de l'endommagement dudit système, contrairement à celle des clôtures, qui repose sur la perte de continuité électrique associée à la rupture d'un câble. Autrement dit, on cherchait un système qui pouvait être rapidement réamorcé et remis en marche après inspection et désobstruction du site, à l'inverse des clôtures existantes, qui sont difficiles à réparer et empêchent le dégagement rapide de la voie.

Ce projet a donné le système de surveillance des éboulements par EMFD. Ce dispositif émet une série continue d'ondes électromagnétiques dans un milieu de transmission (un câble), qui forme une boucle entre l'émetteur et le récepteur. La vitesse de propagation, ou de transmission, des ondes est déterminée par les matériaux à proximité du câble. Toute modification de la vitesse de propagation est déterminée par comparaison de la phase du signal émis avec la phase du signal reçu. Lorsqu'un bloc rocheux tombe à proximité du câble, les ondes ralentissent et il en résulte un glissement de phase. Et un glissement de phase rapide indique une obstruction possible de la voie. Le câble de détection est relativement peu coûteux, facile à réparer, rapide à installer et compatible avec les activités sur la voie ferrée, y compris le déneigement.

Un certain nombre de problèmes opérationnels restent à résoudre. Ainsi, les essais présentement en cours révèlent un taux relativement élevé de déclenchements aléatoires, taux qui doit impérativement être abaissé avant que le système puisse être fonctionnel. Il y a lieu, également, de repenser le câble afin de le rendre plus robuste.

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1 INTRODUCTION

1.1 Existing Technology – Slide Fences

Railways running through mountainous terrain are subject to natural hazards from rockfalls, landslides, avalanches and washouts, and currently deal with the threat of rockfalls, landslides and avalanches by using slide fences. The existing slide fence technology involves a “fence” composed of posts and parallel horizontal wires. The wires are spaced every 6" to 18" on the posts. Examples of typical slide fence locations are shown in Figure 1.

Figure 1 Typical slide fence location

When falling objects such as rocks come into contact with the fence, they break wires or pull open a spring-loaded contact, causing the signalling system to restrict train speeds through the slide zone. These restrictions remain in effect until the fence is repaired. As a result, in order for falling materials to be detected, they must first damage the slide fence, which must then be repaired before it can detect another falling object. Generally, the problems with slide-fence technology are as follows:

- Fences need frequent repairs because of damage as a result of their operation. They must also be taken down and reconstructed whenever rock scaling is required in the area. Furthermore, fences are prone to false activations that require repair.
- Because of the location of slide fencing, maintainers must work in potentially hazardous conditions when repairs are necessary.
- During the time a fence is inoperative, trains are required to travel at restricted speed, resulting in delays to rail traffic.
- Constructing a slide fence is labour intensive, and anchoring posts in rock is expensive. Fence construction costs can be as high as $200/ft.

1.2 Relevant Research

From 1990 to 1992, Transport Canada in partnership with Canadian National Railway completed a basic evaluation of an improved technology for developing a rockfall detection system. This research project identified a number of potential problems that needed to be addressed if the technology were to meet railway industry requirements. In 1997, Canadian Pacific Railway, Canadian National Railway and SAIC, in conjunction with Microlynx Systems, formed a partnership to develop a new system that would improve on the identified deficiencies in existing systems. The electromagnetic field disturbance (EMFD) rockfall detection system is the result of this joint effort. Transport Canada supported the research and development phases.

1.3 Project Overview

A three-phase development project was initiated.

Phase 1: Development of an alpha test system to:
  gather field and laboratory test data;
  confirm the feasibility of the technology application; and
  test and define performance and configuration of subsystems, the results of which would be applied to the comprehensive testing of the proposed system.

Phase 2: Installation of a fully operational beta/pilot system to:
  confirm system design effectiveness;
  test performance against prescribed performance criteria; and
  operate with existing slide-fence technology in parallel applications.

Phase 3: Installation of a functional stand-alone system.

This report outlines the results of Phase 1 and the initial stages of Phase 2 of the development project. The remaining stages of Phase 2 are still in progress.

1.4 Potential Benefits and Functional Requirements

In order for a solution to the problem presented by rockfall hazards to be considered an improvement over systems currently in use, it must:

be more economical to construct;
be less expensive to repair and reconstruct;
reduce the track time required to physically remove accumulated debris;
avoid the costs associated with slide-fence removal; and
introduce safer conditions for maintenance personnel.

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

> detect objects that are hazardous to train movements with the same or a greater degree of accuracy as existing slide fences without interfering with rail operations;
>
> minimize both the probability of rocks exceeding the specified size from entering the detection zone undetected and the occurrence of false (non-hazardous) activations;
>
> reduce the time spent by maintenance personnel in hazardous areas repairing the system and establish a situation where all repairs can be done at grade level;
>
> have a reduced per-foot installation cost so more areas can be equipped with the system; Installation should not require extensive site preparation.
>
> continue to function after a minor event and accommodate remote resetting to minimize train delays. In other words, the first train into an area where detection has occurred would proceed into the detection zone prepared to stop for an obstruction. If the alarm were caused by a non-obstructive event, the system would be reset and subsequent trains could proceed at track speed.

2 EMFD ROCKFALL DETECTION SYSTEM OVERVIEW

2.1 System Components

The EMFD rockfall detection system consists of the following key components and subsystems:

System Processor
RF Transceiver
Sensor cable with protective carrier
Lead-in cables and baluns

2.2 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. It also allows remote interrogation of the system to facilitate the resetting of alarms, adjustment of parameters, interrogation of system operations, downloading of new software, and uploading of stored data.

2.3 RF Transceiver

The RF Transceiver board controls the electromagnetic field around the sensor cables. If the field is disturbed, the RF Transceiver board receives the information and passes the data to the System Processor for analysis. If warranted, the System Processor declares an alarm and activates a relay output. The RF Transceiver board is connected to the sensor cables and provides detection in a zone measuring up to 200 m in length.

2.4 Sensor Cable with Protective Carrier

During the very early stages of this work, a sensor cable topology that was derived from the cable systems used for perimeter security applications was tested. This original system used two “leaky” coaxial cables, one as a transmitter cable, and the other as a receiver cable. Holes in the shields of the two cables allowed a small amount of energy to couple from the transmit cable to the receive cable, and this coupled energy established a detection field near the cables. An intruder changing the coupling would result in a detectable signal. A cross section of this original cable topology is shown in Figure 2.

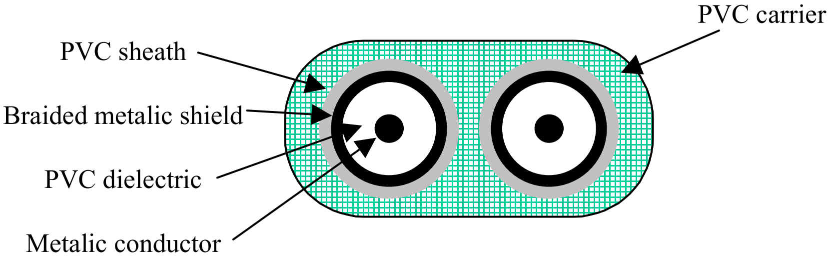

Figure 2 Cross section of original coupled cable topology

A number of significant disadvantages were associated with the use of this type of cable system for use in detecting rockfalls in a railway environment. Fundamental limitations include:

> The coupling field is periodic and thus has nulls and peaks in the detection response. A rock landing in a null would have a much lower probability of being detected than a rock landing in a peak.
>
> The detection sensitivity drops with increased distance along the cable from the sensor circuits. This can be overcome to some extent by increasing the coupling factor as distance is increased; however, there are limits to how much this can be increased, and this tapered cable design increases the cost of the cable substantially.

There were also some operational limitations to the coupled cable approach that might be overcome by redesigning the cable:

> The PVC used to make the cable is difficult to work with and becomes very rigid at low temperatures. In addition to making it difficult to install or repair the cable, the rigidity makes the cable very prone to mechanical stresses that can result in false alarms.
>
> The graded nature of the cable makes it difficult to determine what kind of cable to use for repairs. If a longer length of the wrong coupling is used, it would compromise the performance of the complete system.

To overcome the limitations of the existing cable technology, Microlynx developed a new, recently patented cable topology that uses a single, non-coaxial cable.

The new cable topology is a custom design consisting of two balanced conductors spaced approximately 5 cm apart. The principle behind this topology is that an object coming close to the cable will modify the electrical properties of the cable, resulting in a change in phase of the signal travelling down the line. This change in phase, if it is large and rapid enough, is detected by the system. The software filters out the slow changes caused by environmental factors such as temperature fluctuations and precipitation.

To protect the sensor cables and ensure consistent conductor spacing, a custom rugged rubber extrusion has been designed and manufactured. This extrusion has been developed to optimize and maintain the spacing of the sensing conductors, maximize conductor protection and minimize maintenance efforts. A cross section of the rubber cable carrier is shown in Figure 3.

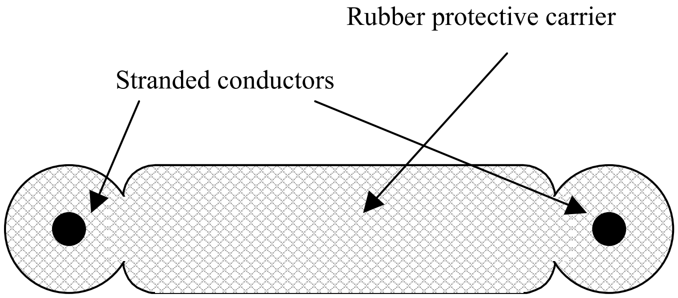

Figure 3 Cross section of new cable topology with protective carrier

2.5 Lead-in Cables and Baluns

Standard low-loss coaxial cable is used to connect the RF transceiver to the sensor cable. This coaxial cable is "unbalanced", in that it has a ground (the shield) and a "hot" canter conductor. In contrast, the sensor cable is "balanced", in that it consists of two identical conductors. Therefore, baluns – **BAL**anced-to-**UN**balanced circuits – are used to convert between the unbalanced coaxial cable and the balanced sensor cable.

2.6 Principle of Operation

The EMFD rockfall detection system senses very small changes in the electromagnetic field set up by the system. These changes can be caused by rockfalls, landslides and washouts, as well as by "noise" factors such as railway traffic, animals and changing environmental conditions. The system works by sending a continuous series of electromagnetic waves down a transmission medium (cable) configured in a loop between the transmitter and receiver. The velocity of propagation, or speed of transmission, of the waves is determined by the material close to the cable. Any changes in the velocity of propagation are determined by comparing the phase of the transmitted signal to the phase of the received signal. A rock landing near the cable will slow down the wave and result in a phase shift. A rapid phase shift indicates a possible obstruction on the track. The principle at work is the same as the bending of light when it goes from air to water. The density (and dielectric constant) of water is greater than that of air. As a result, the wave bends (slows) as it makes the transition from air to water (most noticeable when viewed at an angle).

The EMFD rockfall detection system seeks to maximize the detection of changes in the environment (arrival of rocks/chunks of snow) in the vicinity of the transmission medium by using a conducting path that is responsive to nearby changes. However, this must be done in a controlled manner to minimize activation by random external (noise) factors. In other words, the system must transmit along a medium that allows interaction with the surrounding environment while sensing changes that indicate potential rockfall, avalanche or landslide hazards.

The field is established by transmitting a radio frequency (RF) signal on a special transmission cable that is sensitive to its environment. When the EMFD rockfall detection system receives an RF signal modified by its environment, the signal is filtered to remove unwanted interference, amplified, and compared to an internally generated constant reference signal. Any changes in the field will result in changes to the received (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 a received signal indicates that an event has occurred.

2.7 EMFD Rockfall Detection System Configuration

The most basic system configuration consists of a Master Unit, which is the minimum configuration that can operate as a detection system. Through the addition of Remote Units, the basic Master Unit system can be expanded 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 EMFD rockfall detection system are shown in Figure 4.

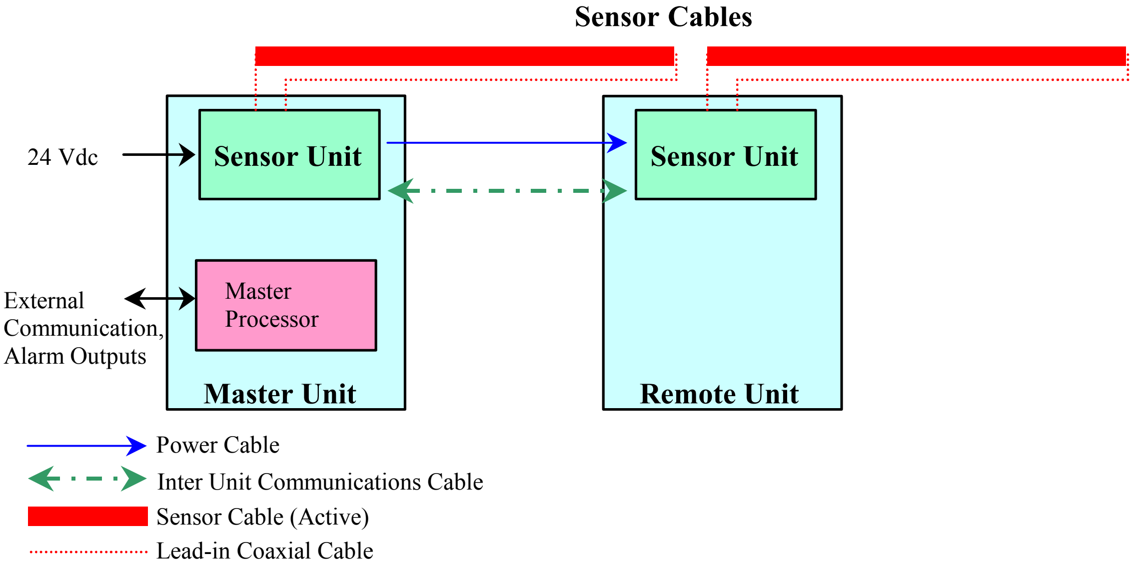

Figure 4 EMFD rockfall detection system components

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; and lead-in coaxial 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 sensor cable, as well as power and communications cables.

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 active sensor cables. This allows great flexibility in the configuration of a particular system.

Figure 5 shows a typical minimum EMFD configuration using a Master Unit with two active sensor cables installed. This configuration provides coverage in two directions.

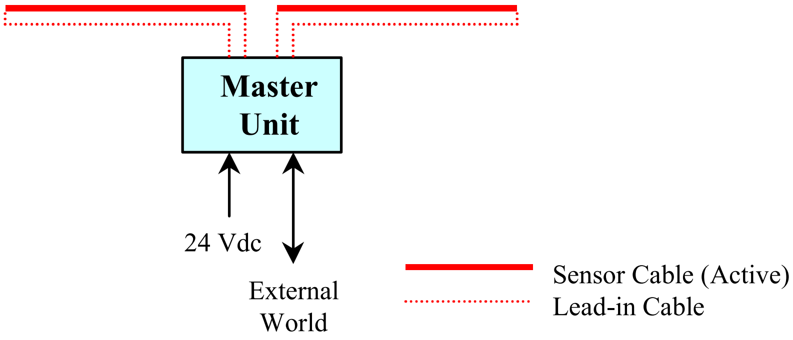

Figure 5 Master unit with two active sensor cables for extended length coverage

Figure 6 shows an example of an expanded system where a Master Unit controls two Remotes located at one side of the detection area. Remote Unit #1 is configured with an expanded detection zone to provide enhanced detection capability at locations where this is required (e.g, for centre-track and track-edge protection).

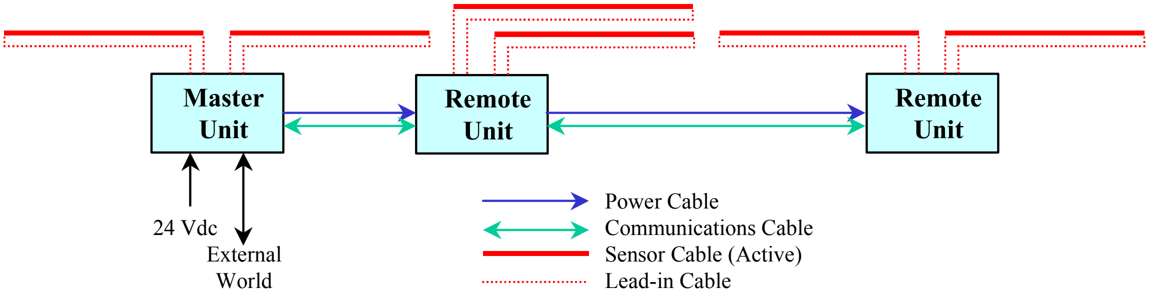

Figure 6 Master and remote configuration with centre and edge detection at one remote

3 ALPHA TESTING SETUPS AND TEST RESULTS

3.1 Tests Conducted

Two prototype systems were installed and tested in 1998. These systems were used to gather field and laboratory test data, confirm the feasibility of technological applications, and test and define subsystem performance and configuration. 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 CNR installation at Lasha, near Lytton, B.C., is shown in Figure 7. Both sites initially used the original coupled-coaxial sensor cable topology.

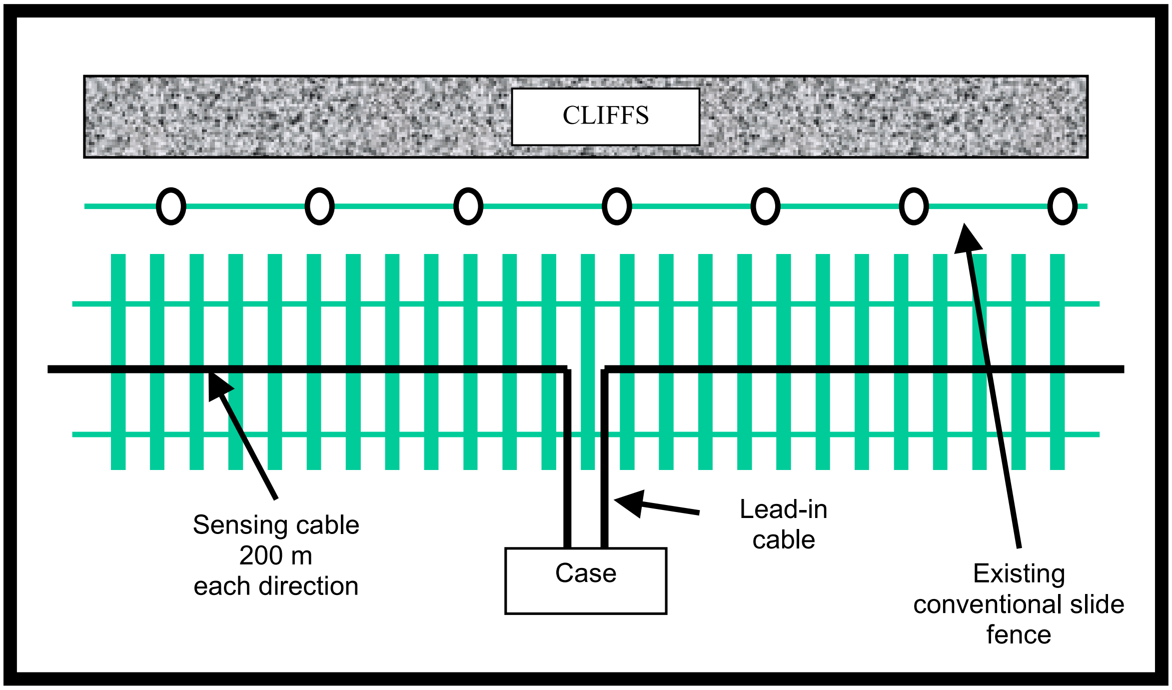

Figure 7 Overview of CNR *Lasha installation*

Each alpha test system consisted of a computer storage unit (a case), which also housed 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 CNR Lasha installation used sturdy high-density polyethylene (HDPE) conduit to protect the sensing cable. Since CNR uses concrete ties at this location, the conduit was periodically attached to the ties using metal hooks anchored to the ballast. There were two active cable runs, one heading east and one heading west. Originally, each run was approximately 200 m long. In an attempt to improve sensitivity, the west run was cut during the testing process to approximately 123 m.

Photographs of the case and installation are shown in Figure 8.

Figure 8 *EMFD rockfall detection equipment at* CNR *Lasha.*
The protective conduit for the cable is visible between the rails at left.

3.2 Preliminary Field Test Results

The EMFD rockfall detection system is able to detect events on both wood and concrete ties. Concrete ties appear to decrease sensitivity to a given event; however, they also reduce background noise. This means it is feasible to use the EMFD rockfall detection system to detect events occurring on concrete ties.

A number of options exist for terminating the cables at the far end of the system. These include terminating the cables with 50-ohm resistors, looping them back on each other, and leaving them open-circuit. In tests, the loop-back configuration was best able to detect a barrel at the outside of the rail.

It does not appear to be possible to compare the signal before and immediately after a train passes to provide some level of protection while the system resets itself after train passage. This is because the cable shifts as a result of vibrations caused by the moving train. Improved cable mounting techniques to reduce settling may help this situation.

The 1998 tests are an excellent source of data but also present issues requiring further exploration:

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 solutions require further testing to optimize.

Cable performance, protection and long-term maintenance issues. These were addressed through additional field testing.

3.3 Cable Test Results

The conducting medium, the cable, is key to this project. Previous research efforts used an expensive, graduated leaky coaxial cable. However, a successful railway application of the technology requires a cable that is compatible with the “Railroad Environment”, which means that the cable should be:

- extremely rugged and able to withstand being run over by tracked equipment;
- reasonably easy to install;
- easy to repair, even during inclement winter weather conditions; and
- 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 issues and railway requirements, the coaxial cable was found to have too many deficiencies. Considerable effort was spent investigating alternative cable arrangements and topologies. The result was the development and testing of an improved sensing cable topology – a configuration consisting of 5 cm parallel twin conductors. This configuration was selected for the following reasons:

- The sensing area around the cable is maximized and controlled.
- The sensing area minimizes uncontrolled external influences that might cause unnecessary activations, while minimizing noise and null effects.

The cable tests were performed at CPR’s Alyth Yard. These tests were also used to fine-tune and improve test procedures, and to improve system operation prior to implementing Beta system testing (currently ongoing).

3.4 Cable Topology Revisions and Results

The revised cable topology consists of two balanced conductors spaced approximately 5 cm apart. For the Alyth installation, 1" x 3" graded cedar planks were used. These were notched with a saw blade, allowing the conductors to be held in place by the notches. Figure 9 provides a cross section of the Alyth prototype cable assembly.

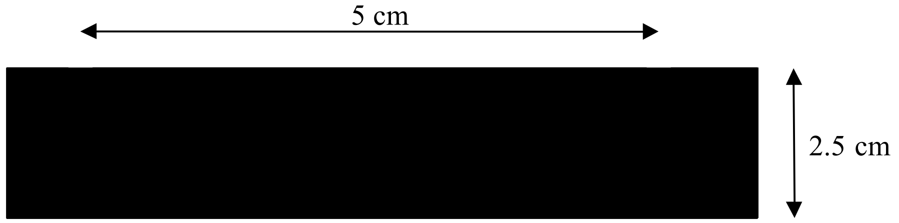

Figure 9 Cross section of beta cable prototype

The principle of this topology is that an object coming close to the sensing cables will modify the electrical properties of the cables, resulting in a change in phase in the signal travelling down the line. If this change in phase is rapid enough, it is detected by the system. The software filters out slow changes. For the Alyth test system, approximately 100 ft. of active cable were mounted at the outside edge of the ties. One end was connected to the transmitter, the other end to the receiver using standard RG-58 coaxial cable. Television baluns were used to connect the coaxial cable to the test cable.

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 and repeatable performance measurements. The tiles were held off the cable with two sections of 2" x 4". This spacing was used to ensure that the electrical effects alone were being observed rather than the mechanical (micro phonic) effects; that is, the tiles never touched the cable. A string was attached to the stack of tiles, allowing 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" space 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 to minimize the detection of mechanical effects. Test results are shown in Figure 10.

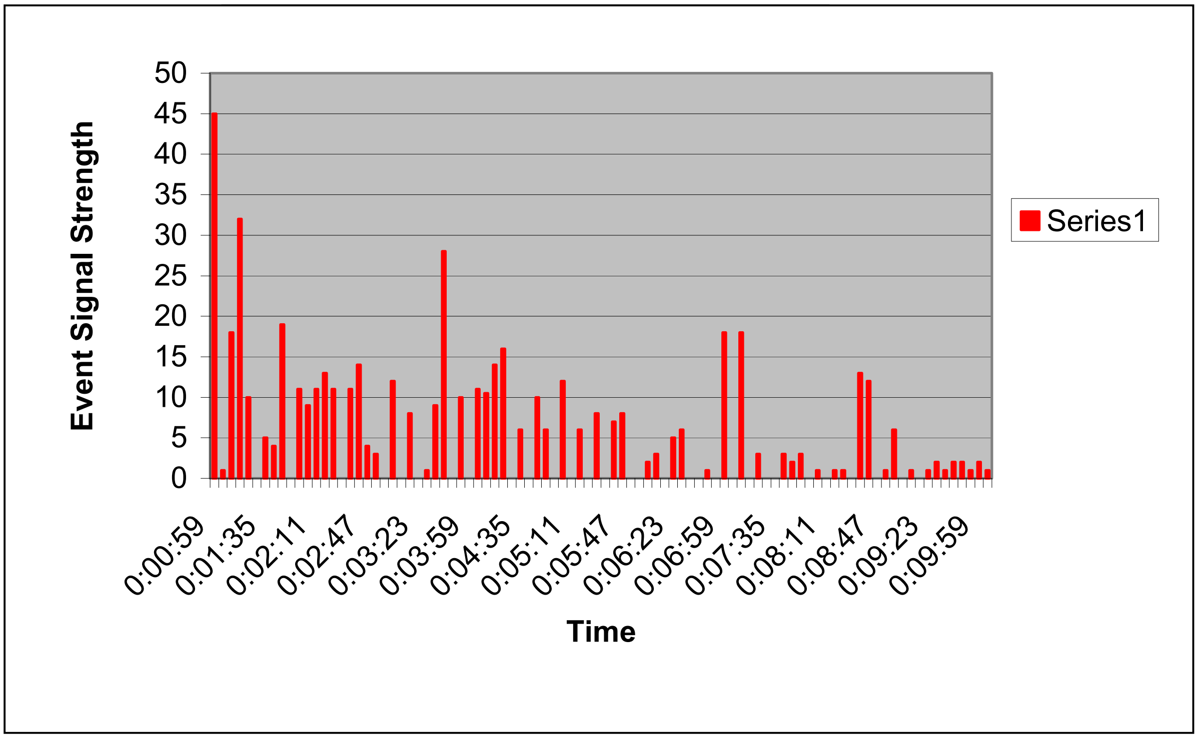

Figure 10 Detection of response of the Alyth test system

As illustrated, the error signal was, in general, cleanly detected by the system. The average background noise signal measured was approximately 0.25 on the scale used, with a peak background over 10 minutes of 2.1. In other words, setting the detection threshold to indicator level 5 should virtually eliminate false triggers due to random noise. The detection amplitude should, in theory, be constant 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. However, there is also a trend to decreased sensitivity with distance that is not explained by the model of the cable. Further investigation will be required to determine the cause of this decrease in sensitivity.

4 PROJECT RESULTS AND RECOMMENDATIONS

4.1 Project Results

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

> The EMFD rockfall detection system is capable of providing the required level of detection sensitivity. The system is able to detect a 12" x 12" x 12" object with a fairly high degree of accuracy (when measured over a set timeframe). This object size is substantially smaller than the 18" x 18" x 18" target objective. A larger rock can be detected with a higher degree of accuracy, especially when the electromechanical effects are taken into consideration. What is required now is further product development to produce consistently accurate detections.
>
> Based on the measured losses, it is predicted that the active cable can be extended to over 100 m without difficulty. This must now be tested.
>
> Detection field range was small – approximately 5 cm – but multiple low-cost parallel runs of cables can be used to customize the detection zone to meet specific site requirements while ensuring that the system detects rocks of the size hazardous to train operations. This results in a system that is not prone to false activations caused by rocks falling a safe distance from the tracks. It also results in a system that is not activated by animals walking near, but not on the tracks. A clearance diagram with possible detection zones is shown in Figure 11. More product refinement is required in this area.
>
> Long-term testing in a relatively quiet section of CPR track shows that there is an unacceptably high level of unexplained false triggers. Further work is required to isolate the cause(s) of these false triggers and develop procedures or algorithms to reduce or eliminate them.

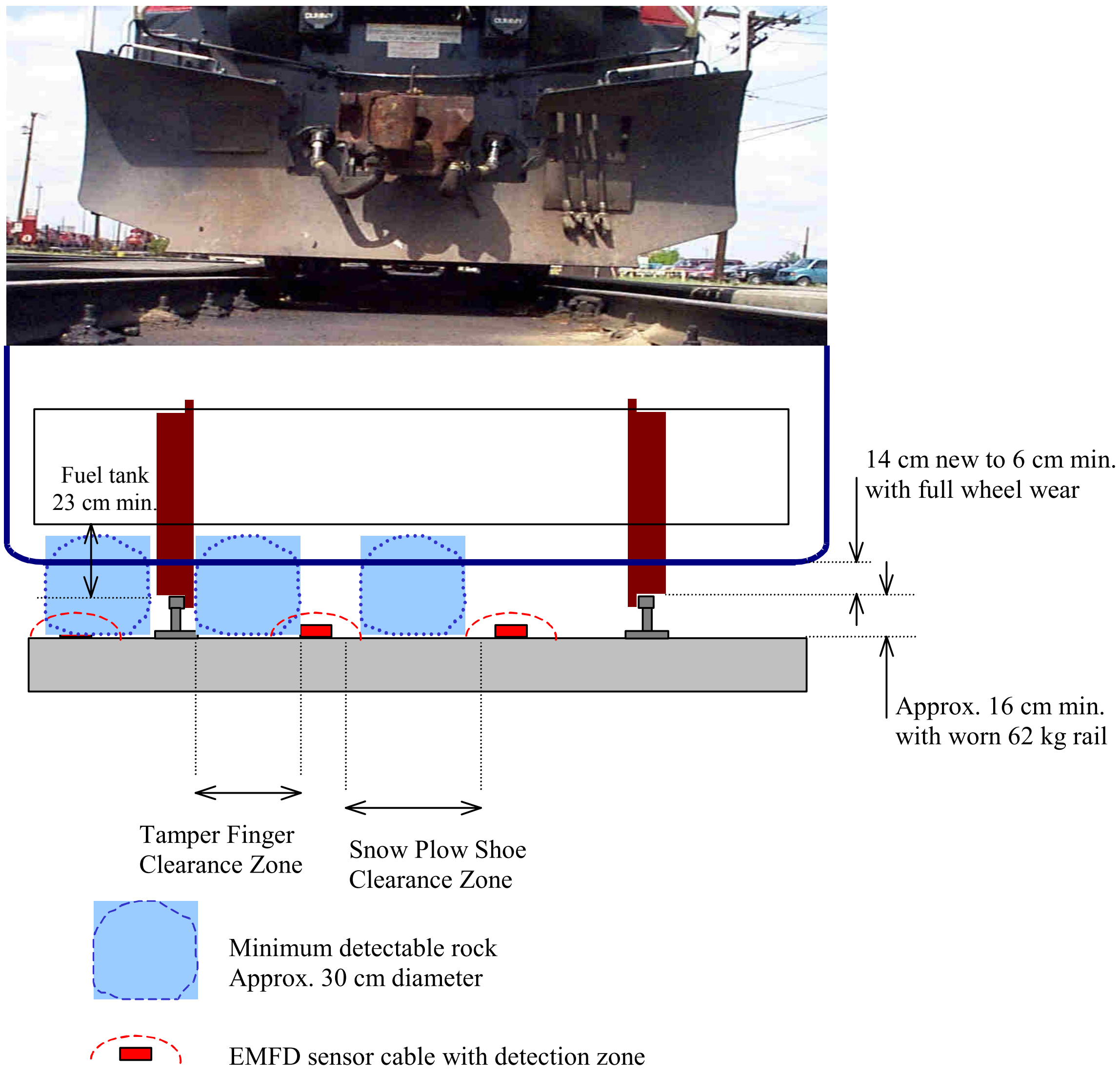

Figure 11 SD90MAC Locomotive Clearance Diagram, showing possible cable location options (not to scale)

4.2 Project Recommendations

It is recommended that:

> The remaining stages of Phase 2 (continued testing of the system against established performance criteria) and all of Phase 3 (implementation of a stand-alone system) be pursued.
>
> Product development and refinement activity be undertaken in conjunction with the electronics developer.
>
> Software processing problems be addressed via comprehensive testing and troubleshooting, and identified deficiencies targeted.
>
> The Electromagnetic Field Disturbance Rockfall Detection Project be extended.

Preliminary results indicate that a safer, more efficient, and more cost-effective rockfall detection system is emerging.

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