

# Broken Rail Detection: An on-board solution for track monitoring

Baier, Martin<sup>1</sup>, Niven, Justin<sup>2</sup>, Blair, Stewart<sup>3</sup>

<sup>1</sup>Siemens Mobility Pty Ltd, Perth (Australia)

<sup>2</sup>Siemens Mobility Pty Ltd, Perth (Australia)

<sup>3</sup>Siemens Mobility Pty Ltd, Perth (Australia)

## Summary

The ability to detect broken or badly cracked rail from revenue trains in near real time transforms the way that the rail is monitored for major rail defects. This technology opens up opportunities to enhance the safety and operations of a railroad by overcoming significant limitations in the performance of current detection technologies. This paper discusses how the on-board broken rail detection system works, interacts with operations, and creates new opportunities for technical development.

**Keywords:** Broken Rail; Safety; Rail Infrastructure; Maintenance

## 1 Introduction and Motivation

A rail network relies on the integrity of track infrastructure to ensure safe and reliable operation. Effective monitoring and maintenance are required to ensure that the required levels of safety and reliability are maintained. A key aspect of track maintenance is the detection and repair of rail breaks.

Traditionally, track circuits have been the most widely used solution for real time broken rail detection. In fixed block signalling systems, the track circuits have provided the primary function of train detection and a secondary function of the detection of broken rails based on the electric continuity of the rail. The shift towards modern communication-based signalling systems has removed the requirement for track circuits, leaving their only remaining application as rail continuity monitoring. In this role track circuits have some key limitations including:

- Inability to determine precise break location within a section
- Will only detect complete breaks with separated ends
- Inability to monitor through all areas within a turnout
- Considerable capital and maintenance cost

A variety of alternative solutions to detect broken rails are subject to research programs or already available on the market. Some of them are:

- The fibre optic detection technology proposes to attach fibres to the rail with epoxy or tape. If the rail breaks, the fibre will break as well which will be detected by a computer system. Even though the technology works in principle, [1] identified multiple disadvantages. Some of them are: Mounting requires substantial effort and cost as the rail surface must be clean and dry and epoxy set up time takes a long during cold weather; the system is extremely fragile and can easily be damaged during installation or track works; and the cost increases with the length of the infrastructure.
- Distributed Acoustic Sensing is a technology which detects the acoustic feedback of a passing train through a fibre optic cable which is installed adjacent to the track, at a defined distance. Wheels passing a rail break will generate an acoustic pattern which will be observed via the fibre and then be analysed by a computer. Even though the technology is more robust than above fibre optic solution in terms of installation and maintenance, [2] found in a field test with three different systems that detection accuracy and false positive rate are not acceptable for operational use. Furthermore, [2] found that the systems encountered problems when trains were passing at low speeds, or when trains were accelerating or decelerating.
- Another class of solutions to detect broken rails propose to inject acoustic / ultrasonic signals into the rail at one place and sense the signal at another place. Failure in signal detection is an indicator for a broken rail. These systems have limited range, and rely on the continuity of the rail, which is not always given, for example at rail joints. As such, the effort to install infrastructure along the track is significant and counteracts the effort of reducing trackside infrastructure with communication based signalling systems. Further disadvantages that such systems share with track circuits are the inability to determine precise break location and the inability to monitor through all areas within a turnout. Furthermore, [3] indicates that only complete breaks can be detected reliably.

- To avoid installing new equipment along long sections of track, and to avoid the installation and maintenance cost that comes with this, on-board broken rail detection solutions are an obvious option. Ultrasonic measurement devices, possibly combined with eddy-current measurements are a reliable option to detect various kinds of track damage or defects. While these technologies offer an ideal measurement methodology for regular rail inspection from dedicated inspection vehicles, implementation on multiple revenue-generating trains aiming for a replacement of track circuits is not practical. This is primarily due to limitations of top speed of around 60 km/h and the continuous consumption of ultrasonic coupling agent as described in [4].

As a summary, the on-board systems based on ultrasonic technology are quite limited in the maximum speed of the rolling stock, so that they're not suitable for continuous or near real time inspection without heavy disturbance of railway operations. Infrastructure based systems have the inherent disadvantage in capital expenditure and life cycle cost scaling with track length which inhibits the business case for large networks. Furthermore, depending on the specific technology, detection accuracy, localisation precision of breaks, false positives rates, or reliability and robustness of the system might be problematic for an efficient implementation.

Hence, as an alternative solution for the detection of breaks in rail networks not requiring track circuits for signalling purposes, Siemens Mobility has developed on-board Broken Rail Detection (BRD). The system doesn't require any change to the rail network infrastructure and hence cost does not scale with the length of the network, it is not reliant on complete separation of rail breaks, and it can determine the exact position of breaks.

## 2 Broken Rail Detection

The essential part of the patented system is the sensor (Figure 1) that detects the break in the rail. Each train equipped with a Siemens Mobility BRD system includes a pair of sensors, mounted to the bogie directly above each rail in the shadow of the wheel. Each sensor is comprised of a permanent magnet that produces a magnetic field coupling with the rail (Figure 2), and an array of magnetic field strength sensors which measures the coupling effect.

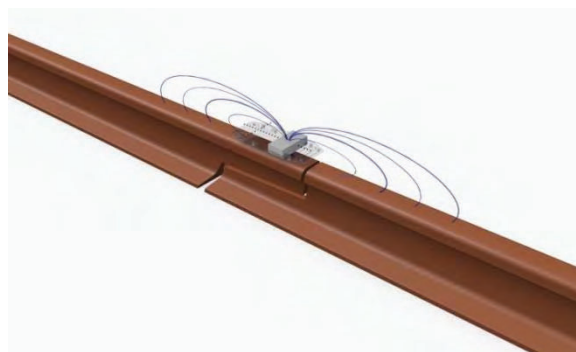
These sensors are continuously scanning the rail, measuring the magnetic coupling between the sensor and the rail. The sensor output is speed independent and does not rely on any additional sensory inputs to detect a feature in the rail. This reduces the probability of incorrectly identifying a feature due to potential data stream matching issues. The

sensor has been extensively tested with a sampling rate of 12.5kHz. Implemented installations work reliably at maximum line speeds of 80km/h, while the system is designed for a maximum detection speed of 120km/h. High speed applications are under investigation.



*Figure 1: Siemens Mobility Broken Rail Detection (BRD) sensor*

The data from the two sensors is fed into a central processing unit which has a real time analysis algorithm. This algorithm filters out the inherent magnetic noise in the rail steel as well as the other signals that are created by the sensor's dynamic movements. The remaining signature is analysed for intensity to determine if it meets the characteristic of a broken rail. If the rail is continuous and it has no defects in it, the magnetic field is constant, and the sensors see no variation.



*Figure 2: Flux field coupling between the BRD magnet and the rail head*

The data stream from each sensor head is processed independently. The sensor is designed to optimise the signal to noise ratio of a rail discontinuity while being able to filter out noise using both the physical arrangement of the sensor and an intelligent algorithm.

Auxiliary data is essential for the second process of correlating the location of the feature in the rail. A GNSS and tachometer is utilised to determine the location on the rail. This could be substituted with a balise and tachometer in a situation where there are underground applications.

A radio communications system is required to connect the on-board system and the Back Office System (BOS). Due to the need to have a flexible system, the location of the decision making process has been focused on reducing the data traffic. As such the on-board system has the analysis algorithm running in real time so the only real time data traffic is of detection information, location information and a health heartbeat. Furthermore, the detection information is captured in a parameterised way which keeps the individual detection data size to a minimum. It would be feasible to reduce this even further by having the track map on-board but this adds the complex requirement then to keep the on-board map up to date, which may have the opposite effect by burdening communications.



*Figure 3: Axle end generator for power supply*



*Figure 4: Solar panel for power supply*

Obviously, the sensor itself as well as data processing and transmission require a power source which is a commodity on locomotives and passenger coaches. However, in freight applications power is not always readily available. For this reason, the Siemens Mobility BRD system optionally comes with a power management system. This consists of a

battery pack and an axle end generator (Figure 3) which continuously transforms kinetic energy from the rolling stock to electric energy to charge the battery.

To guarantee that the system is operational right away even after a long stop of the train during which the battery could discharge, additional solar panels maintain the battery charged even in such operational situations (Figure 4).

### 3 Detection Capability

The Siemens Mobility BRD sensor has been engineered so that it is highly sensitive to the detection of broken rails. However, it is desensitised to other track anomalies that would otherwise cause a false alarm. The sensor has the ability to reliably detect a break in the rail that is greater than 0.5mm in width. This includes missing head, other incomplete breaks, and complete breaks with a residual electric contact that a track circuit would otherwise fail to detect. An example of such is shown in Figure 5.



*Figure 5: Rail break with residual electrical contact*

Additionally, due to the nature of a break interface, even when in compression, a rail discontinuity will be detected. This scenario would not be detectable by other detection methods such as track circuits due to the presence of a closed electrical circuit. This feature was evaluated in a lab test:

To provide a reproducible standard, the ends of two rail sections were machined to be able to produce a repeatable and ideal broken rail. This was used to characterise the response with varying gap widths. Figure 6 shows the response to the varied gaps of the two broken rail samples, one simulated break and one real sample taken from an in-field broken rail. This showed several important characteristics of the signal. Primarily, the results between the two samples are highly consistent. Additionally, even with machined

rail ends on the simulated break sample under compression, there is still an observable response from the sensor due to the material discontinuity. There is also a roll off in signal amplitude for gap widths greater than approximately 2mm.

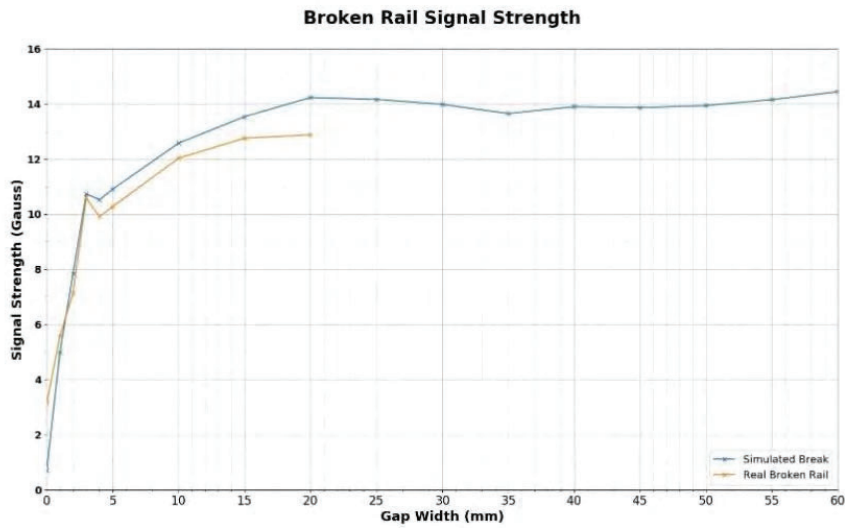


Figure 6: Broken rail signal strength over gap width

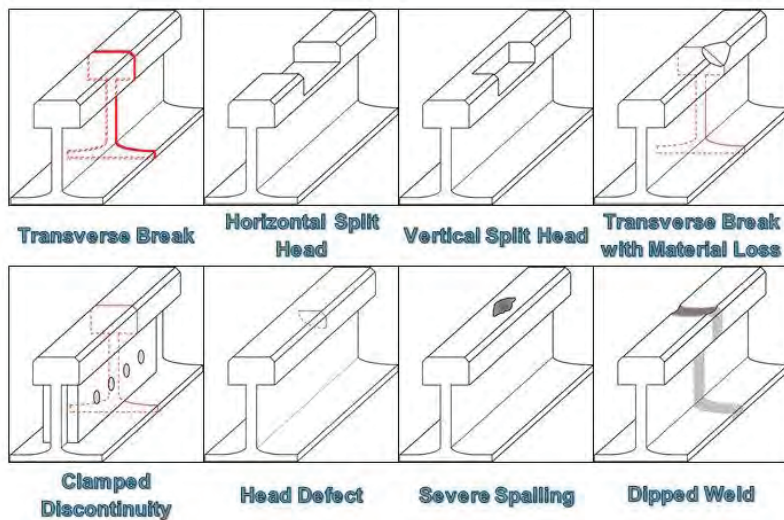


Figure 7: Detectable features in the rail

Due of the nature of the fractured surface, real broken rail samples do not mate in a smooth way. Broken rail sections cut from the track and tested in a state of compression were found to have a signal strength equivalent to approximately 0.5-2mm gap width on the machined break sample, this varied according to how well the two ends were able to mate together.

As the sensor specifically observes rail discontinuities, it can also detect IRJs, plated or clamped joints, frogs and any other rail end like components in the network. These can be used as a health metric of the systems in service as they provide a detection rate and positive feedback that the system is performing as expected. Furthermore, the system is capable of detecting a wide variety of rail defects beyond the common transverse break, this is depicted in Figure 7.

## 4 Integration into operations

The Back Office System (BOS) can be coupled directly into a signalling system to provide an integrated verification and monitoring process. This allows the BOS to take corrective actions in preventing following trains from passing over detected broken rails. With this level of integration two-way communications are required where the signalling system won't release the track following the train unless the Siemens Mobility BRD system confirms the rail is clear of breaks.

The BOS requires a track map with all the benign features that the Siemens Mobility BRD sensor will detect in the network. In situations where the track map is known with poor accuracy or significant dark territories, it can be constructed by collecting the data from the sensors over successive runs. Once the track map is established, it is used to verify further detections in the rail by the Siemens Mobility BRD units.

The track map requires continuous management to ensure the features that are being identified by the sensor units are aligned correctly as any misalignment will result in a detection being reported as a broken rail. This can prove challenging in an operational environment as most track databases are not kept up to date in real time. However, as the rail industry moves more towards digitisation of infrastructure and assets, there is significant motivation to ensure that data quality and timeliness is addressed, so this is not a challenge that is seen as creating a negative impact on an operator.

The BOS provides a flexible interface which can be used for integration to any signalling system. However, some specific implementations of interfaces such as to the Siemens Mobility Vicos OC operations control system but also to third party signalling systems are already in development or in operation.

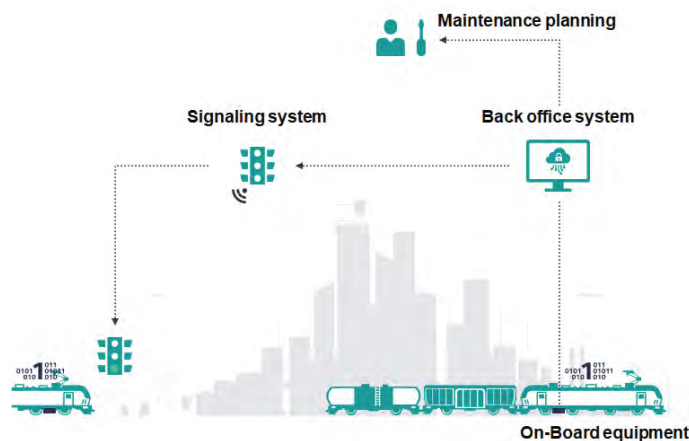


Figure 8: Feedback into the signalling system

Developed to SIL-1 standards, the Siemens Mobility BRD system fulfills necessary safety standards to work within an ecosystem of rail infrastructure components.

## 5 Next steps of development

Even though the Siemens Mobility BRD system is being rolled out as a product in customers projects, there is further potential of the technology which can be elevated by additional product features.

### 5.1 Satellite Communication

One big advantage of the Siemens Mobility BRD system is that it doesn't require any trackside infrastructure for operation. This makes it particularly interesting for large networks where the cost of trackside solutions rapidly reaches high values. A typical example is railroads from iron ore mines to ports that go through long distances of thinly populated desert. However, the availability of a cellular communications network which is necessary for real time feedback into the signalling system is also very limited in these areas.

To allow real time feedback for such applications, a system extension with a satellite modem is being developed which will allow the data to be sent from on-board systems to the BOS via a satellite communications network and landside satellite gateway. By using standard satellite internet hardware and standards, the additional cost for the operator is kept to a low level, especially in comparison to establishing alternative communications pathways available throughout a rail network.

## 5.2 Visual Images of Broken Rails

As discussed, the Siemens Mobility BRD system allows detection of features in the rail which will not be picked up by other technologies such as track circuits. Even though the number of false positives with less than 1 per 1,000,000 km is extremely low, the high accuracy of the system might lead to detections where a complete stop of operations could be exaggerated and a less impacting operational measure such as speed reduction could be the more economical reaction to a detected defect. Today, the effort to make this decision is quite high as a track inspection team must be mobilised to visibly confirm the location and nature of the new artefact.

Therefore, a prototype of an additional ruggedized camera system on the train is in evaluation. The target is to provide the operator with a view image of the detected artefact. If this image allows the operator to clearly classify the artefact, lighter operational measures could mitigate the impact of a complete stop of operations.

## 6 Conclusion

The Siemens Mobility BRD system is a reliable platform and enabler for the next generation of signalling systems that also presents a significant improvement over current broken rail detection methods. The choice of technology and method of application has eliminated previous issues with other attempted on-board broken rail detection solutions.

The Siemens Mobility BRD solution is also in line with the rail industry's direction of installing autonomous asset monitoring systems on revenue rail vehicles and is therefore another step towards making rail assets smarter and more connected with operations.

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## Authors



**Baier, Martin**

Segment Head MRX at Siemens Mobility  
21 Barker Street, Belmont, WA 6104, Australia  
[baier.martin@siemens.com](mailto:baier.martin@siemens.com)



**Niven, Justin**

Head of Infrastructure Measurement Engineering MRX at Siemens Mobility  
21 Barker Street, Belmont, WA 6104, Australia  
[justin.niven@siemens.com](mailto:justin.niven@siemens.com)



**Blair, Stewart**

Deputy Head of Engineering MRX at Siemens Mobility  
21 Barker Street, Belmont, WA 6104, Australia  
[stewart.blair@siemens.com](mailto:stewart.blair@siemens.com)