Railway EMI impact on train operation and environment

A. Morant, Å. Wisten, D. Galar, U. Kumar
Division of operation, maintenance and acoustics
Luleå Tekniska Universitet, LTU
Luleå, Sweden
amparo.morant@ltu.se, ake.wisten@ltu.se,
diego.galar@ltu.se, uday.kumar@ltu.se

S. Niska
Electrical Power systems
Trafikverket
Luleå, Sweden
stefan.niska@trafikverket.se

***Abstract*:** **Several studies in Sweden have looked into railway electromagnetic interference (EMI) either to discover the source of the interference or to determine if the equipment in the system is performing properly. The movement of rolling stock along an electrified track produces certain EMI events. Transient electromagnetic fields are produced in the signalling system when the train leaves the neutral section of the overhead power line and enters the powered section. These transient EM fields are mainly produced by the engine. The track's infrastructure system has been tested for EMI events, but this phenomenon affects the surrounding environment as well, up to at least 10 meters from the track. The infrastructure is designed so that the return current from locomotives should go through the running rails, but occasionally the ground acts as a conductor, transmitting current to areas that are distant from the rail. The paper reviews the status of Swedish railways with respect to electromagnetic compatibility. This TREND project is a joint project with 7 FP EU.**

Keywords: Railway, EMI impact, signalling system, train operation, train environment.

I. INTRODUCTION

It is important for maintenance support personnel to understand interruptions and faults in railway infrastructure, as for example, electromagnetic interference (EMI), so that they can manage their time more effectively.

A general trend towards increased traffic flow, higher speeds, more trains per hour, longer trains and heavier axle loads demands more powerful engines and stronger currents in the supply lines [1]. The complexity of the railway system increases when more electronics are used [2, 3, 4]. The environment of railway tracks is exposed to magnetic and electric fields from trains, the railway power supply systems, nearby electric power transmission lines [5], and other sources [6]. Consequently, the radiated and conducted electromagnetic emissions from railway systems are increasing over time [7, 8]. The combination of more sensitive electronic circuits [9], and stronger electromagnetic noise, containing higher frequencies, may make the railway system as a whole more sensitive [10].

Systems for traffic signalling are crucial for both safety and efficiency. If anything goes wrong in the signalling systems, all the lights should switch to red. While this creates a safe environment, it can also cause delays. Although traffic signalling systems have very high reliability, there have been unexplained phenomena, arguably caused by disturbances from passing trains [11]. Because of very high reliability goals, ongoing work aims at the highest possible security [12].

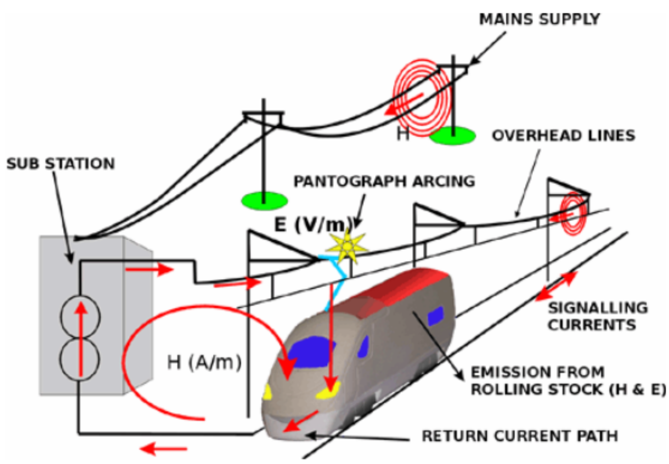

Figure 1. EMI influences between Railway – Infrastructure - surroundings.[13]

As the electromagnetic environment at the railway track is demanding, electromagnetic interference (EMI) is likely to occur [10], and electromagnetic compatibility (EMC) becomes a main goal. EMC covers a wide range of phenomena, including inductive noise in parallel communication lines, impulse noise from lightning and traction transients, the production of hazardous voltage under step and touch conditions, and the appearance of stray currents (Fig. 1). The interaction between power-electric controlled rail traction drives, power systems and track signalling systems is an important issue, since in-band harmonic interference current flowing in the signalling system can result in degradation of the system's performance, including, in the worst case scenario, unsafe failures [14]. Knowing how the railway system behaves is important, as better understanding will result in better EMC and EMC designs [15, 16, 17, 18].

II. EMI IN INFRAESTRUCTURE CAUSED BY ROLLING STOCK

The process for approving trains to operate specific routes in terms of their EMC is complex, and the current EMC requirements for the rolling stock and railway infrastructure are not clearly specified. Thus, a more global view of the electromagnetic interface between the railway infrastructure and trains is needed. This also applies to re-equipping the infrastructure which is both onerous and costly for infrastructure managers. In both cases, generic EMC compliance limits are required.

A. EM effects on signal systems caused by rolling stock

Trafikverket and Bombardier performed the following study in 2009. Ösmo, a station on a high-use track between Stockholm and Nynäshamn (16kV AC 16.7Hz), was being reviewed, as the shuttle train had problems with a specific signal (signal 22) on the track. Several times the signal switched to red just in front of the train, and the train had to make a brake intensive emergency stop. The train control central (TCC) found there was interference in the train control system circuits, as several trains were occupying the track in the station. After a short time, the signal's indications switched off again. On the train, this interference could show as a balise fault.

The study discovered that an insulated section of track in Ösmo was 475m from the cabinet that controlled signal 22, and 430m from where the cables entered signal 22. A transient electromagnetic field occurred when the driver turned on the power to the locomotive after leaving the insulated section of track.

The transient EM field was measured on the cables in the signalling system using a Dranetz analyser; the trace can be seen in Fig. 1.

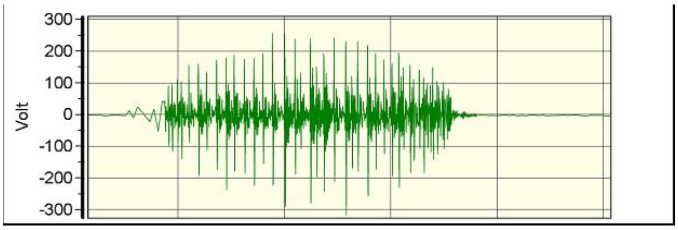

Figure 2. Measurements on a Drantez analyser in the signal system when the driver turns up the power of the locomotive.

Abnormal behaviour was also detected by using a track circuit sniffer installed for the signalling system. The train was stopping randomly (from three times per week to three times per hour) in front of red lights due to the errors in the signalling.

The starting of a locomotive from a specific train was identified as the main source of the EM waves that affected the signalling system. Transient EM fields produced at this time caused the interference.

EM interference created by the starting of a locomotive is an issue of the railway system in interrupted (both intentional and non-intentional) sections of a powered track. The starting excites the electrified railway, generating transient EM interference in adjacent signalling systems. In this case, this was accentuated by the repeated locomotive starting necessitated by the insulated track section at this particular location.

To prevent the repetition of such occurrences, the insulated section of track and OHL was connected to the power system and energised to avoid the locomotive's random stops and starts and to prevent the undesired transient EM fields.

While powering the whole section prevented these transient EM fields, however, similar problems could remain elsewhere.

B. ATC (Automatic Train Control) radio interferences on track switch detectors

Studies have paid special attention to the devices that are crucial to the safety of the train. For example, switches and crosses decide different trajectories for the vehicles, with a view to avoiding the collision with other rolling stock circulating on close tracks. The sensors and actuators which are responsible for these movements are critical, especially given their susceptibility to undesired EMI.

In a 2005 case analysis by LTU and Trafikverket (former Bankverket) [19], the rail switch position detector indicated position "left" instead of "right" due to interference from the ATC transmitter (Fig. 2). The switches had one detector to check the position of the track and the direction of the train crossing it. This detector was giving wrong information and causing a misunderstanding between the train command and train direction.

The upper part is fixed to the rail switch's blade as shown in Fig. 3. When the blade is moved from left to right, the upper part follows it from position "left" to position "right". The lower part is fixed to solid ground and does not move. It is connected to a cable with three wire-pairs: one for input 24 V DC, one for output port 1, and one for output port 2 The picture shows the position of the upper unit, where the output signal changes from "left" to "right".

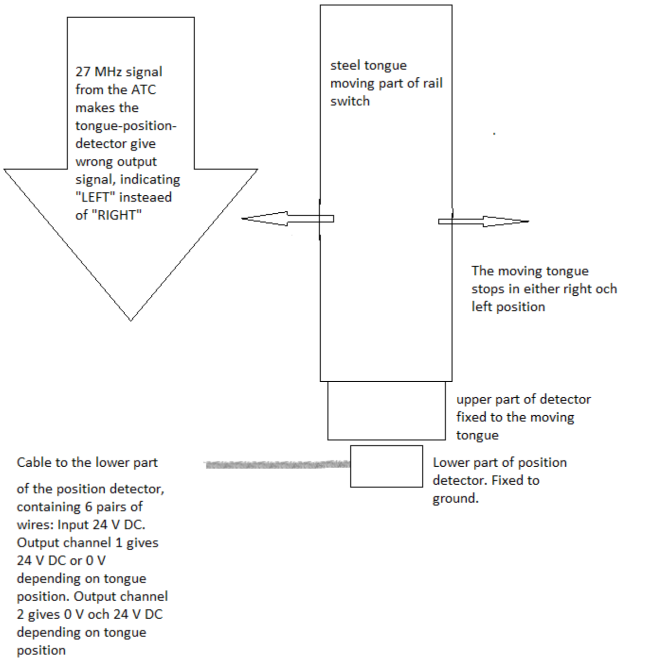

Figure 2. Rail switch position detector indicates “LEFT” instead of “RIGHT” due to ATC signal from passing train.

When the switch’s blade position detector was tested, it proved to be sensitive both to injected high frequency voltages and to radiated electromagnetic fields, for approximately the same frequencies.

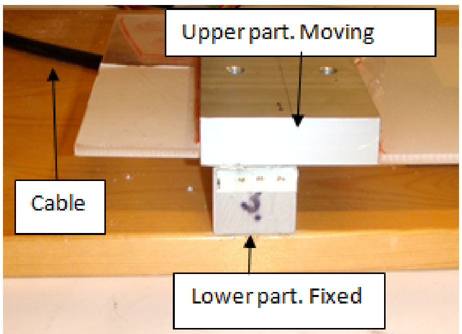

Figure 3. Photo of the switch’s blade position detector in the laboratory

Since these detectors are essential to the safety of the train, they were sent to LTU EMC lab for testing. The tests found that the detector was sensitive to many radio frequencies from DC to 300 MHz. The main EM source was the ATC radio transmitter located under the front of the active head of the locomotive.

These detectors had previously been tested and carried the CE marking. However, they were not properly tested for the interferences produced by the ATC and were being interfered with. Consequently, the detector state was altered and showed wrong information, thereby compromising safety.

TABLE I. SWITCH’S BLADE POSITION DETECTOR. RESULTS FROM TEST FOR RADIATED IMMUNITY. DETECTOR IN POSITION “RIGHT” THROUGHOUT THE TEST

EM test field	port 1	port 2	comment
No field. Undisturbed unit	0 V	24 V	Normal output
27.8 MHz, Field corresponding to 14 W transmitter at 1 m distance	24 V	0 V	FAULTY, “right” becomes “left”
27 MHz, Field corresponding to 14 W transmitter at 1 m distance	24 V	0 V	FAULTY, “right” becomes “left”
Magnetic flux 0 Hz - 3 Hz	24 V/0 V	0 V/ 24 V	FAULTY, alternates “left”-“right” with the same frequency
Magnetic flux 4 Hz - 6 Hz	24 V – 0 V	0 V / 24 V, alternating at random	FAULTY, alternates at random
19 MHz, 27 MHz -80MHz,	24 V Or other voltage	0 V or other voltage	FAULTY Position “right” becomes “left” output voltages wrong
135 MHz – 175MHz 10 V/m, 80% mod 1 kHz	24 V or other voltage	0 V or other voltage	FAULTY, output voltages wrong

To prevent this undesired behaviour, all detectors were removed and replaced with safer ones that were EMC tested. The new detectors work properly, indicating that a lack of testing of the previous ones was the reason for the problem. In future, the failure immunity tests should be performed at all low frequencies from DC to 80 MHz, (not in standards) and according to standards for 80MHz – 1000 MHz (and upwards).

C. EM noise in the Swedish Railway.

A 2004 study by Trafikverket (former Banverket) and LTU [20] investigated train-induced EM noise in the electronic systems in close proximity to the railway tracks.

Problems in the signalling system had been observed; it was necessary to determine a method to make measurements safely. The investigation was designed to get a closer look at how systems in close proximity to the track were functioning. As this was an information gathering exercise to understand possible EMI mechanisms, no remedial action was required. Trackside equipment had been assessed according to EN50121, but the assessments did not take into account the equipment’s close proximity to the track i.e. less than 3m, as mentioned in EN50121-4.

The study performed measurements on detector systems for flat wheels, hot brakes, and hot bearings. It did not measure the signalling system, due to the potential risk of harming important security/safety functions. It chose to measure the detector systems for the following reasons:

1) There had been reports of false signals in the detector systems, such as indicating passing axles and reporting trains that did not exist, or giving alarms for a “system down”.

2) Detector systems must be reliable so that correct decisions can be made by the driver, i.e. whether or not to stop a train and/or take a certain car out of traffic.

3) The cables used in the detector system are the same type as those used in the signalling system; therefore, some of the conclusions could possibly apply to the signalling system.

To determine possible reasons for failing electronic systems in the railway environment, electromagnetic noise was studied at two detector sites in northern Sweden. The first site, Notviken, is used to detect flat wheels using strain gauge bridges; the second, at Sunderbyn, has two IR-detector systems: one for hot bearings and another for locked brakes. The Notviken section is fed by a booster transformer system (BT), while the Sunderbyn section is fed by an autotransformer (AT) system. The electromagnetic noise at the detector sites was measured under winter and summer conditions.

To separate conducted and radiated transient electromagnetic fields, the detector system measurements were completed with a cable set-up using a twisted pair of shielded cables (type BELDEN 1250A). The twisted pair of receiving cables was set up parallel to the rails, at 1m, 3m, and 6m intervals from the nearest rail, at the same height as the upper level of the rails. At the far end, each twisted pair was loaded with 150Ω resistors, weather-protected and electrically shielded. While testing was being conducted to find the best possible locations, cable locations in the middle of the track and very close to one rail were evaluated but later not used because of very low signal levels. A few tests with 15m BELDEN cables starting at a distance of 6m from the rail, and running at 45 degree and 90 degree angles to the track were also tested, but not r pursued, again due to very low signal levels. The cable locations are detailed in Fig. 4. Each part of the twisted pairs was connected to the centre conductor of a 10 m, RG223 cable running through specially made aluminium lids covering the window-openings of the shed used for measurement. The indoor length of the RG223 coaxial cables was 2.3m, giving a total length of 12.3m. Measurements were carried out using a Tektronix TDS 7254 oscilloscope inside the shed, where the common mode voltages of each part of a twisted pair could be recorded. The differential mode voltages were calculated by subtracting the two common mode voltages of a twisted pair.

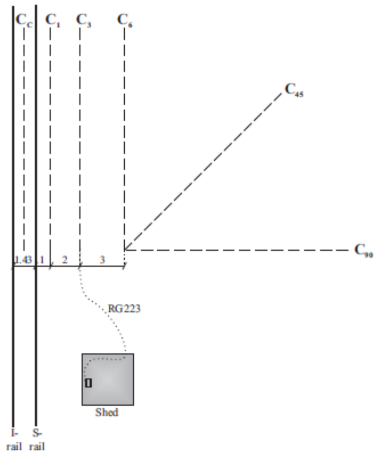

Figure 4. Measurement schema

Measurements to detect radiated disturbances were performed using parallel BELDEN 1250A cables contacted by RG223 cables. Cable locations in the middle of the track (CC), parallel to the rails at 1m (C1), 3m (C3), and 6m (C6) distances from the nearest rail, and cables starting at a distance of 6 m from the rail, and running at 45 degree (C45) and 90 degree (C90) angles to the track were also tested.

III. EMI IN ENVIRONMENT CAUSED BY ROLLING STOCK

The permissible electromagnetic emissions from the railway to the outside world are clearly defined by industry standards. For example, EN 50121-2 provides guidance on maximum emission levels that can be measured at the railway boundary fence. Induced ground currents due to environmental magnetic or electric fields cannot be neglected in the railway sector, as amplitudes are powerful enough to affect surrounding facilities, including buildings, houses etc..

A. Ground currents due to lack of isolation of track circuits

In a study case performed in 2002 by LTU and Trafikverket (former Bankverket), telephones were ringing due to the ground currents created when a heavy train was passing (Fig. 5). When the train was going uphill in Älvsbyn, the locomotive configuration used was three locomotives working at the same time. That configuration caused telephones to ring in the surrounding area up to one kilometre from the railway. This happened every night when a train was going up the hill and three locomotives were working.

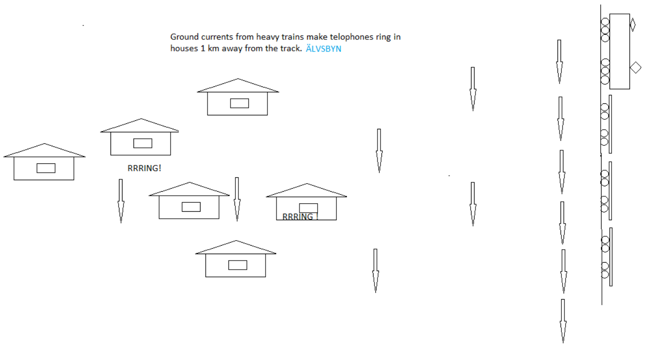

Figure 5. Ringing of telephones due to ground currents from passing heavy trains.

Ground currents were produced due to several locomotives working together; the return current system was inadequate in these circumstances. Return currents from locomotives should go through the running rails; but when there is a bad earth return path, the ground acts as a conductor, transmitting these currents to distant areas.

Figure 6. Iron rod attached to a copper wire used to measure the voltage difference between the iron rod and the S-rail.

The ground voltage was measured between an iron rod stuck in the ground and the S-rail (the rail used as electric ground for the return current) as shown in the Fig. 6. In the following graphs the distance between the S-rail and the iron rod was 2 meters. The train was pulled by an engine type RC6. The graphs show the voltage variation during more than 8 minutes, starting 130 sec before the engine's passage and ending 355 sec after the engine's passage [21].

TABLE II. OVERVIEW OF THE GROUND VOLTAGE GRAPHS

Time slot (Engine passing at t=0)	**Section number**	**Comment**
-130 to -85 s	1	Max 40 V_{pp}
-75 to -30 s.	2	Saturated at 80 V_{pp}
-20 to - +35 Including the engine passing at t= 0 s.	3	Shows local max. 7 s. before engine passage
+35 to + 80 s.	4	
+90 to +135 s.	5	voltage rising
+145 to +190 s.	6	Voltage rising
+200 to +245 s.	7	Voltage rising Now 80 $\mathbf{V_{pp}}$
+255 to +300 s.	8	Voltage rising. Now 114 V_{pp}
+310 to +355 s.	9	Voltage suddenly drops in two steps. Now 115 V_{pp}

Note that the sudden voltage drop 310 sec after the engine's passing, shown in Fig. 7, occurs because the engine is passing the next transformer.

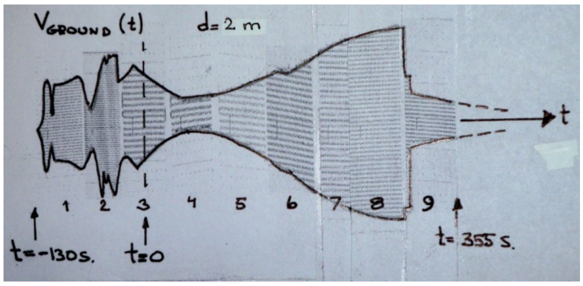

Figure 7. Ground voltage 2 m from the closest rail, to the right of the track, going towards NARVIK, 1529.785 km north of Stockholm. Scale 10 V/div.

Fig. 7 shows the voltage from 130 sec before the engine‘s passage to 355 sec after its passage (maximum voltage approx. 115 Vpp). Fig. 8 shows an expanded graph of the ground voltage, printed on a paper roll.

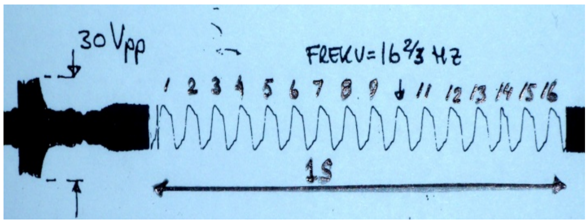

Figure 8. The ground voltage at a distance of 10 m from the rail. Maximum voltage 30 Vpp. Expanded time plot during one second, shows the voltage shape and the 16.7 Hz frequency.

Although the problem was identified, nothing was done about it, given the low criticality of the issue (the only constructions in the area are summer houses, not inhabited full time). Therefore, the issue remains open.

IV. EMI IN ROLLING STOCK CAUSED BY ENVIRONMENT

Sometimes conditions in surrounding areas play an important role in electromagnetic disturbances. The conductivity of the ground due to rain or snowfall or the ability of close surfaces to act as electrical or magnetic mirrors can increase the undesired EM signals produced by rolling stock. Some of these environmental aspects may be created by humans altering the natural electromagnetic properties of the ground or the air. The following case shows the special behaviour of the ground close to mining areas caused by human actions, not by nature.

A. ATC (Automatic Train Control) abnormal behaviour in mining areas

The final products of some mines are small balls of iron called "pellets". When wagons are loaded with these pellets, some fall between the tracks. Once on the ground, due to the ratio of the size of the pellet and the wave length of some signalling systems, these metallic balls convert the surface between the tracks into an electrical mirror reflecting 27 MHz and producing disturbances in transmitted signals. For example, undesired reflections are interpreted by the train as wrong balise messages.

In 2003, LTU and MTAB (mining train operator for LKAB mines) performed a case study in which the ATC transmitter was disturbed by a "heap of iron balls" underneath the locomotive (Fig. 9).

The locomotive stopped where it crossed a heap of iron (composed of pellets that fell in the loading process). The heap of ore was acting as an EM mirror and reflected EM waves were disturbing the system's transceiver. Since the ATC transceiver was less than one meter away from this EM mirror, the disturbances were very high.

To prevent repeat occurrences, the ATC radio is now routinely switched in these mining areas. However, the issue is not solved. This phenomenon is easily applicable to any other spot signalling systems which have to transmit a signal to awaken the balise or the emitting cable.

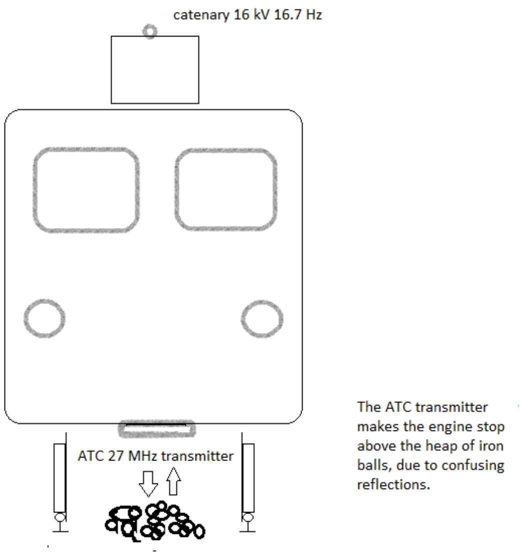

Figure 9. The ATC transmitter disturbed by a 'heap of iron balls' underneath the locomotive.

V. Conclusions

EM disturbances are responsible for a significant number of faults in the railway infrastructure system. Statistics show that as many as 70 % of all the faults can be caused by EMC disturbance.

This paper has introduced some important EMC issues that have a strong impact on rolling stock manufacturers, since they indicate problems in the test site rather than the train. MC European Railway standards like EN-50121 allow manufacturers to self-certify in areas of electromagnetic compatibility [22]. But as the cases described here show, this has not prevented problems.

Finally, the amount of electronic equipment used by the railway has increased, creating new problems. Almost every system is now based on electronics. Given this, a review of the current EU standards for the railway EMC influences is called for.

The next step in research would be to identify the gaps in the railway EMC railway standards.

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