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Analysis of the electromagnetic environment in an extensive railway area

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Abstract. The paper presents the results of testing the electric and magnetic fields across a wide frequency spectrum as unintentionally generated in an extensive railway area. High levels of electromagnetic interference generated in a railway area can cause the malfunction of electrical and electronic devices. The paper presents an electromagnetic environment in the low and high frequency spectra that prevail in an extensive railway area. Special attention was paid to the impact of electromagnetic interference on specific electronic systems.
Keywords: electromagnetic field, spectrum, interference, induction and capacitive coupling
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1. Introduction

A determination of the electromagnetic environment in an extensive railway area should consider the following sources of electromagnetic (EM) interference (EMI):

- Stationary EMI sources: the catenary system, the power line feeding the catenary substations, the power feeders of traffic control systems, and the power feeders of traffic safety systems (which include video surveillance systems and intrusion alert systems).
- Mobile EMI sources: motive power units (electric locomotives, Diesel-electric locomotives, and electric multiple units).

  The electromagnetic environment in an extensive railway area is also affected by the following EMI types [1, 2, 5]:

- External EMI, the sources of which include EM fields generated by power lines feeding the services of a railway station facility, wireless communication base stations, power feeders of outdoor lighting systems in the railway area, and radio-frequency transmitters or radar stations located within the vicinity of the railway area [2, 5, 8].
- Internal EMI, which include the following sources of electric and magnetic fields: electrical equipment in interim operation or being the permanent facilities of the extensive railway area, site power lines feeding LV loads, and electrical and electronic devices of the railway station / platform equipment.

The issue of EMI generated by the catenary system emerged in the early days of radio communication. Even before World War II, many countries had state services to regulate and control EMI. Great Britain established one of these authorities in 1920. Polish research into the effects of EMI on radio communication services and reception began in 1935. In 1937, EMI removal teams were established in the areas of coverage of individual radio stations. In the same year, the Polish Electric Standard, PN/E-58, was published and made effective under the title "Wskazówki usuwania zakłóceń w odbiorze radiofonicznym pochodzących od różnych urządzeń elektrycznych" (Guidelines for removal of radiophonic service interferences from various electric equipment). State-of-the-art electronic devices applied in railway traffic control systems and traffic safety systems are required to be compact (miniaturised), energy-efficient for power consumption, and highly reliable in operation. These restrictions mean that the useful signal levels of these devices are often very similar to the level of EMI generated by mobile EMI sources (motive power units). Continuous diagnostics of the electromagnetic environment is crucial for the introduction of novel high-power equipment and systems [3, 7, 9, 11, 12]. The tasks required to complete the diagnostics of EM fields include identification of EM field sources and the determination of EM field parameters, three-dimensional distribution, and spectral characteristics. The mutual existence and operation of different devices and systems in a single railway area without exceeding the maximum EMI is called electromagnetic compatibility (EMC). EMC is a blanket term for the permissible conditions of the effects caused by external and internal EM fields on the operation of electronic devices and equipment with electronic circuitry. Electronic traffic safety systems installed in an extensive railway area can be affected by EMI in different frequency spectra. Low frequency EMI may affect traffic safety systems by conductive coupling (i.e. from the power supply circuits to data transmission buses). Extremely low frequency EMI can introduce adverse signals in a different fashion: by induction and capacitive coupling (in the near field) and EM radiation (in the far field), see Fig. 1 [1, 2, 5].

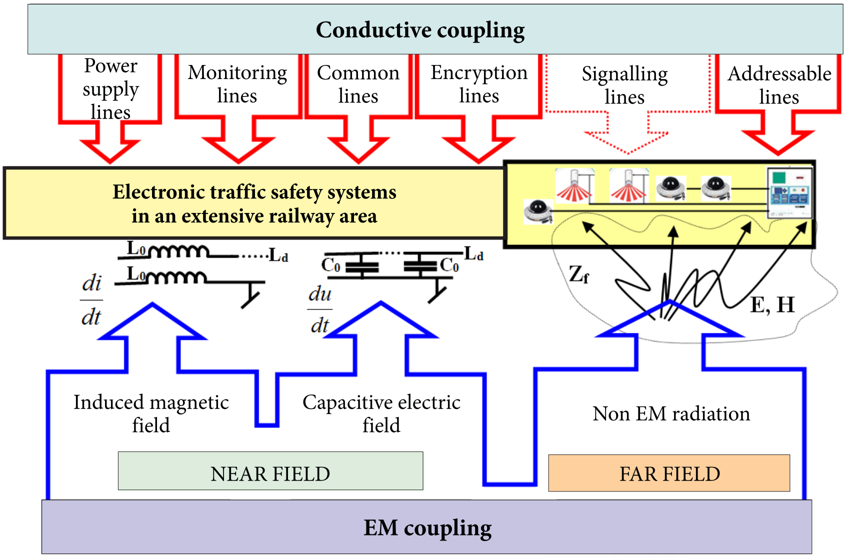


Fig. 1. Effects of EMI on a system installed in an extensive railway area

2. A low-frequency electromagnetic environment in an extensive railway area: test results

The distribution was tested of electric field strength E and magnetic field induction B on an extensive railway area, see Fig. 2. Due to practical concerns related to the tests, the frequency spectra of the tested parameters were conventionally divided into the following:

- ELF (Extremely Low Frequencies) from 5 Hz to 2 kHz;
- VLF (Very Low Frequencies) from 2 kHz to 100 kHz.

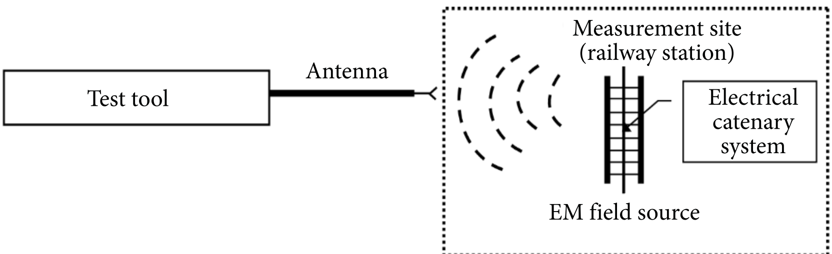


Fig. 2. Diagram of a test station used to measure the electric and magnetic field intensities vs. distance from the tested low-frequency EMI source

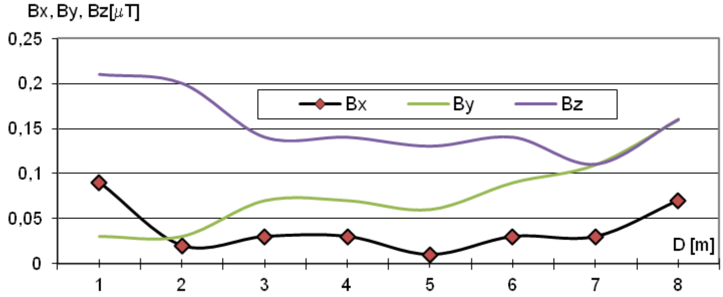


Fig. 3. Distribution of components B_X, B_Y and B_Z of magnetic field induction B measured across Platform 2 of railway station X in the ELF spectrum

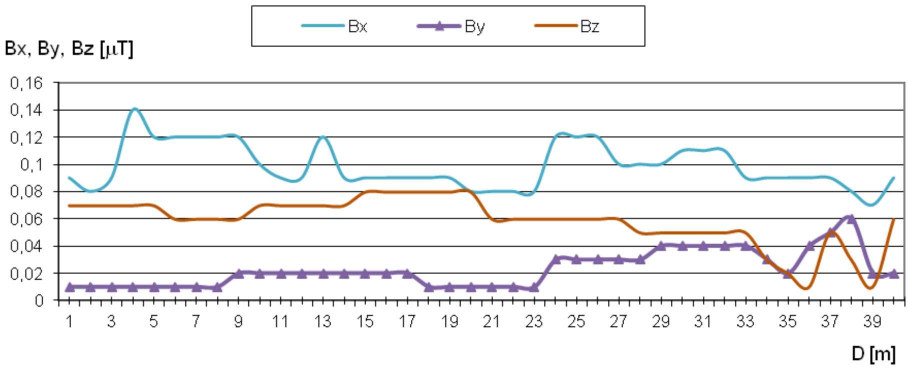


Fig. 4. Distribution of components B_X, B_Y and B_Z of magnetic field induction B measured along Platform 3 of railway station Y in the ELF spectrum

The magnetic field B tests were measured between 8^{00} and 13^{00} hours at the railway station platform under heavy railway traffic and an outdoor temperature of –5°C. Minus temperatures resulted in an increased current load by the catenary system and the power feeders. The measured magnetic field induction B values were directly proportional to the current load of the railway station's power supply system. The maximum value of magnetic field induction B was ~4 m from the catenary system's centreline and reached 0.14 μT. The variation of magnetic field induction B during the test was ± 15%. The variation came from the differences in the load imposed on the catenary system by the electric motive units.

3. Test results of electric field strength E in the ELF and VLF spectra

Electric field strength E was tested in the ELF spectrum and the VLF spectrum. To assess the electromagnetic environment within the railway platforms, tests were carried out across Platforms 2 and 3 and along the platform at a minimum distance of 0.5 m from the platform slab edge. The values of electric field strength E in the ELF and VLF spectra were very low, see Figs. 5 and 6. The maximum value of electric field strength E in the ELF spectrum was E = 33 V/m (Fig. 5) and fell to the background electric field level in the environment not exposed to EMI. Platform 2 featured variations in E, reaching a maximum of 25 V/m at a distance of 5 m.

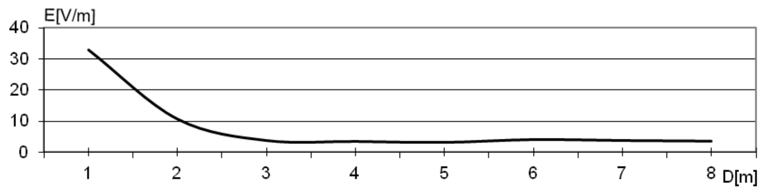


Fig. 5. Distribution of electric field strength E measured across Platform 3 in the ELF spectrum

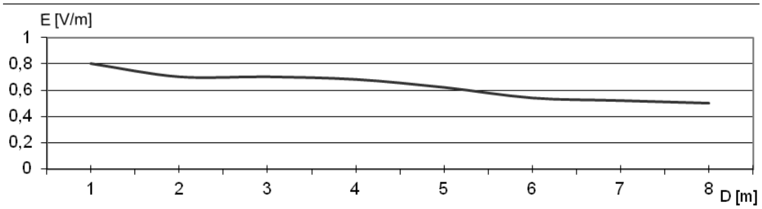


Fig. 6. Distribution of electric field strength E measured across Platform 3 in the VLF spectrum

4. Test results of irradiated EMI in the extensive railway area

Irradiated EMI in the extensive railway area was measured in the frequency spectrum between 150 kHz and 1 GHz. The irradiated EMI levels above 1 GHz feature extremely low amplitudes and their reduction is inversely proportional to the distance from the EMI radiation source; hence, no such tests are attempted currently at frequencies above 1 GHz. The irradiated EMI between 150 kHz and 1 GHz can be tested with three different types of antennas to achieve a full test coverage of the frequency spectrum [1, 2, 5, 12].

The types of antennas follow:

- Frame (loop) antenna, positioned in parallel to the railway track; enables testing the EM field magnetic component H. In this study, an antenna was used compatible in the 150 kHz to 30 MHz spectrum.
- Biconical and log-periodic antennas enable testing the EM field electric component. The measurement was made with the vertical and horizontal polarity of the antenna, see Fig. 7.

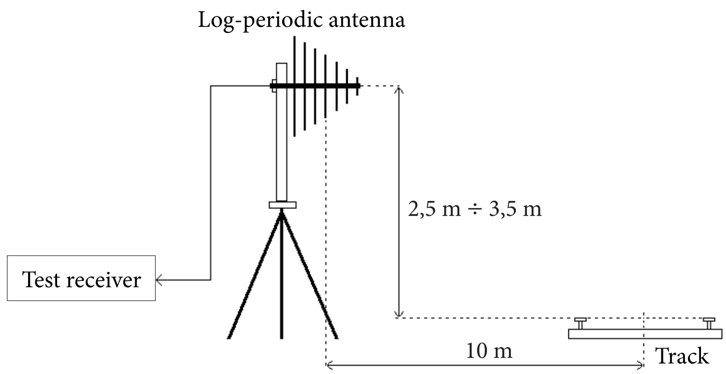


Fig. 7. Diagram of a test station used to measure magnetic field strength H between 300 MHz and 1 GHz

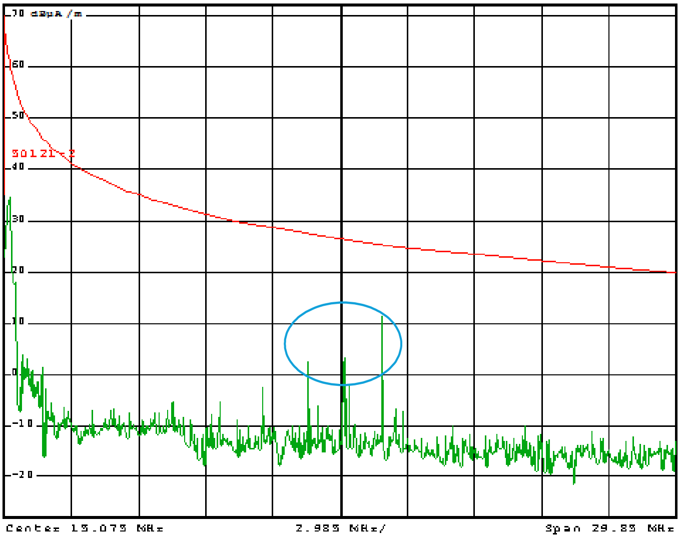
The background EM level was tested in a frequency spectrum from 150 kHz to 1 GHz. The green colour in the charts shows the progress of the background EM level test in specific frequency subdomains, see Figs. 8 to 10. The test was carried out in the extensive railway area, disregarding the effects of mobile EMI sources installed in motive power units.

The following observations were made during the test of the background EM level in the electromagnetic environment in the specific frequency subdomains:

— The EMI limit specified in the standard PN-EN 50121-2 was not exceeded in the frequency spectrum of 150 kHz to 30 MHz. Significant EMI was found only in a band oscillating around 3 MHz; however, the EMI level and frequency was too low to interfere with the operation of electronic systems, see Fig. 8.

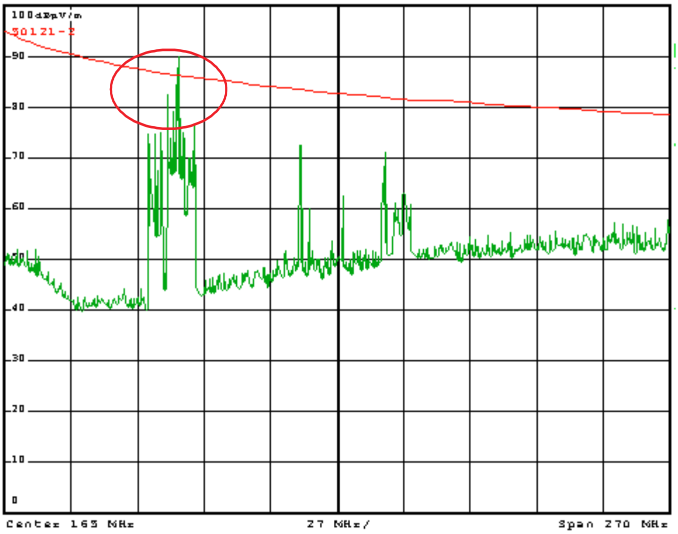
— In the frequency spectrum of 30 MHz to 300 MHz, tested with a biconical antenna and vertical polarity, the EMI limit specified in the standard PN-EN 50121-2 was exceeded. EMI were found in a frequency spectrum between approximately 90 and 120 MHz; the EMI level and frequency might disrupt the performance of the electronic systems in the extensive railway area, see Fig. 9. In this frequency band, certain system connections and long wiring may act as receiving antennas for EMI.

— In the frequency spectrum of 300 MHz to 1 GHz, tested with a log-periodic antenna and vertical polarity, the EMI limit specified in the standard PN-EN 50121-2 was significantly exceeded in two frequency subdomains, 580 MHz and 930 MHz. The amplitude of the EMI was 88 dBμV/m, which might cause interference in the operation of the electronic systems on the extensive railway area. The frequency spectrum from 390 MHz to 530 MHz also featured EMI, although the EMI levels were below the limits established in PN-EN 50121-2. The EMI sources at these frequencies were radar, TV and radio broadcasting stations, navigation equipment and telecommunication equipment, which operate in frequency bands strictly licensed by law.



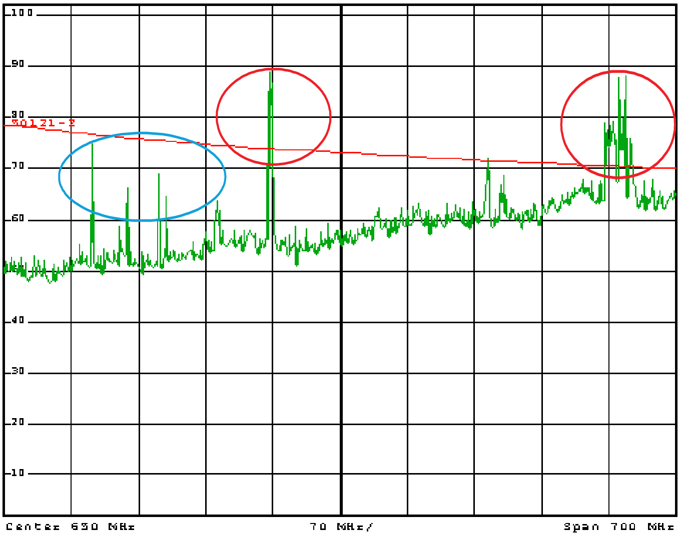
BAND 150 kHz–30 MHz, TLO

Fig. 8. Test of the background magnetic field strength between 150 kHz and 30 MHz



BAND 30 MHz–300 MHz, TLO, POL V

Fig. 9. Test of the background electric field strength between 30 MHz and 300 MHz; vertical polarity of the biconical antenna



BAND 300 MHz–1 GHz, TLO, POL V

Fig. 10. Test of the background electric field strength between 300 MHz and 1 GHz; vertical polarity of the log-periodic antenna

5. Conclusion

Electric and electronic systems commonly used in telecommunication engineering, automation engineering, IT, power engineering, and other industries are very close to one another [1, 2, 5, 13, 14, 15, 17].

The use of integrated circuits in electronic systems in order to reduce the size of electronic devices results in a higher density of electronic circuitry per volume of space, which elevates the risk of EMI.

The design of an electronic system should include its operation in real-life conditions, i.e. in effective proximity of other equipment and devices. This means that control systems should be immune to external EMI sources and cause no EMI (here the terms of external EMC and internal EMC apply) [1, 6, 10, 12, 16].

The tests show that the extensive railway area featured EMI in the electromagnetic environment from the railway catenary system. The levels of EM components, i.e. magnetic field induction B and electric field strength E depended on the location of the measuring point on the platforms. The site of the railway station with a low railway traffic during the test of magnetic field induction in the ELF spectrum 23 to 30 m away from the EMI source revealed an elevated value of $B_{max} = 1$ μT. The level of magnetic field intensity B at railway station Y also reached an elevated value, 0.3 μT. The presence of the local maximum values, of magnetic field induction level B at the railway station, could interfere with the operation of the traffic control system and the traffic safety system (when the area in question features the transmission buses of safety systems, telecommunication lines, and railway traffic control cables) [3, 4, 5]. Magnetic fields with induction B = 0.5 μT already induce unwanted frequencies (at 50 Hz) for TV and computer monitor displays [6, 7, 15]. The distribution of components B_X, B_Y and B_{Z} of induction B of the magnetic field measured along the platforms at railway stations X and Y in the ELF spectrum revealed B values above the background EM field of the environment not exposed to EMI. The average background induction level B at the platforms was 0.1 to 0.25 μT.

The tests completed on the irradiated EMI emissions (i.e. the field background test without any electronic devices or systems in operation in the extensive railway area) revealed violation of the EMI limits established in PN-EN 50121-2. EMI were found in a frequency spectrum between approximately 90 and 120 MHz; the EMI level and frequency might disrupt the performance of the electronic systems in an extensive railway area.

In the frequency spectrum of 300 MHz to 1 GHz, the EMI limit specified in the standard PN-EN 50121-2 was significantly exceeded in two frequency subdomains, 580 MHz and 930 MHz. The EMI amplitude was 88 dBμV/m. This was over the regulatory limits, which might cause interference in the operation of the electronic systems in the extensive railway area. The EMI sources at these frequencies were radar, TV and radio broadcasting stations, navigation equipment and telecommunication equipment, which operate in frequency bands strictly licensed by law [1, 2, 5, 10, 12, 14, 16].

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K. BIAŁEK

Analiza środowiska elektromagnetycznego na rozległym obszarze kolejowym

Streszczenie. W opracowaniu przedstawiono wyniki badań pól elektrycznych i magnetycznych z szerokiego zakresu częstotliwości, które wytwarzane są w sposób niezamierzony na rozległym obszarze kolejowym. Duże poziomy zakłóceń elektromagnetycznych mogą zakłócać pracę urządzeń elektrycznych i elektronicznych, które są użytkowane na obszarze kolejowym. W artykule przedstawiono

środowisko elektromagnetyczne, jakie panuje na rozległym obszarze kolejowym z zakresu małych i dużych częstotliwości. Szczególną uwagę zwrócono na oddziaływanie zakłóceń elektromagnetycznych na wybrane systemy elektroniczne.
Słowa kluczowe: pole elektromagnetyczne, widmo, zakłócenia, sprzężenie indukcyjne i pojemnościowe
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