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ANALYSIS OF EXTERNAL SOURCES OF RADIATED ELECTROMAGNETIC DISTURBANCES AT AN OPEN AREA TEST SITE FOR TRAM VEHICLES

ANALIZA ŹRÓDEŁ ZEWNĘTRZNYCH ZABURZEŃ ELEKTROMAGNETYCZNYCH PROMIENIOWANYCH NA OTWARTYM POLIGONIE POMIAROWYM POJAZDÓW TRAMWAJOWYCH

Abstract

Requirements relating to Open Area Test Sites (OATS) during measurements of radiated electromagnetic disturbances are precisely defined in standard PN-EN 50121-3-1. A significant problem arises during tests of public transport traction vehicles, such as trams and trolleybuses. In these cases, the choice of test site, with some exceptions, is limited to city agglomerations, where most of the tracks and catenaries are located. For this reason, choosing a test location that fulfils general requirements and is exposed to low levels of electromagnetic disturbance emissions from external sources can be difficult. It often requires an analysis of the emission sources and their potential elimination. The article looks at the requirements of applicable standards regarding correct measurements of radiated disturbance emissions. Selected examples of actual results of electromagnetic background emission with their interpretation are also presented.

Keywords: electromagnetic compatibility, electric traction, tram

Streszczenie

Wymagania dotyczące otwartego poligonu pomiarowego (OATS – Open Area Test Site) podczas badania zaburzeń elektromagnetycznych promieniowanych są ściśle określone w normie PN-EN 50121-3-1. Duży problem pojawia się przy badaniu pojazdów trakcyjnych komunikacji miejskiej, takich jak tramwaje czy trolejbusy. W tych przypadkach wybór poligonu pomiarowego, z małymi wyjątkami, jest ograniczony do aglomeracji miejskich, gdzie usytuowana jest większość torowisk i sieci trakcyjnych. Z tego powodu wytypowanie miejsca do badań spełniającego wymagania ogólne z jednoczesnym zapewnieniem niskiej emisji zaburzeń elektromagnetycznych od źródeł zewnętrznych może być utrudnione. Wymaga to często określenia i analizy źródeł emisji oraz ich ewentualnej eliminacji. W artykule zwrócono uwagę na wymagania norm dotyczące prawidłowego pomiaru emisji zaburzeń promieniowanych oraz przedstawiono wybrane przykłady uzyskanych wyników emisji elektromagnetycznej tła wraz z ich interpretacją.

Słowa kluczowe: kompatybilność elektromagnetyczna, trakcja elektryczna, tramwaj

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1. Introduction

The requirements that must be met by open area test sites during measurements of electromagnetic disturbances are clearly specified in standard PN-EN 50121-3-1 [3]. Where a main line vehicle is tested, it is easier to ensure appropriate test conditions, as such measurements are usually carried out on railway lines. Along a stretch of a railway line, it is possible to select a location where the external infrastructure is limited in size and the distance to the other traction stock units is appropriate. A significant problem arises if one needs to test urban vehicles, such as trams or trolleybuses [1, 2]. In such cases, the selection of test site, with few exceptions, is limited to urban agglomerations where most tram tracks and overhead lines are installed. That is why selecting a test location that meets general requirements and, at the same time, is not exposed to external sources of high levels of electromagnetic disturbances can be a difficult task. Such a task often requires for emission sources to be identified, analysed and possibly eliminated. This article looks at the requirements set out in applicable standards, governing correct measurement of radiated disturbance emissions and examines selected examples of results of electromagnetic background emission measurements as well as providing an interpretation thereof.

2. Requirements for measurements of radiated electromagnetic disturbance emissions

Measurements should be performed in well-defined and reproducible conditions, as described in standard PN-EN 50121-3-1. The contributions of other parts of the railway system (e.g. substations, signalling) and of the external environment (e.g. power lines, industrial sites, radio, television and mobile phone transmitters) to the measurements should be known and taken into account during the tests.

The test site should meet the so-called "free space" requirements within the existing constraints of the railway environment. The separation distance from trees, walls, bridges, tunnels or vehicles should be a minimum of 10 metres for urban vehicles and a minimum of 30 m for main line vehicles. The measurement point should be at the midpoint between the masts, on the opposite side of a single-track line or, in case of a double track, on the side of the track which is being used, and if the railway system is powered by a third rail - on the same side of the track. The minimum clear length of the overhead conductor on both sides of the measurement point should be 500 m for urban vehicles and 3 km for main line vehicles. There should be no overhead conductor discontinuities, substations, transformers, neutral sections or section insulators etc. along the track section during the test.

In the event that resonances occur in the overhead line at radio-frequencies, it should be noted, and it may be necessary to change the test site. Prior to measuring emission from the vehicle tested, it is necessary to determine or measure the contribution of the substation and to verify whether or not there are overhead power lines or buried cable lines carrying high voltage in close proximity. No other railway vehicle should be operating within a distance of 2 km for urban vehicles and 20 km for main line vehicles.

If these conditions are not possible, the background (ambient) noise before and after each emission measurement of the vehicle under test should be recorded. If the above conditions are ensured, only two background (ambient) noise measurements at the beginning and the end of the test series are sufficient. If at a specific frequency or in a specific frequency range the background (ambient) noise is higher than the limit values less 6 dB, the measurements at these frequencies are not taken into account, but should be noted in the test report.

For the purpose of allowable limits, the presence of "physically-remote, but electrically-near" vehicles out of the test zone is regarded as insignificant when considering radio noise. This recognises that although remote vehicles are sources of noise, the attenuation with distance for the higher frequencies is normally high. When fields at the lower frequencies of measurement are considered, the attenuation is low and all vehicles within the zone of influence (which may extend over several km) can affect the noise level.

When testing at 10 m, it is important to recall that the induction field and the radiation field have different characteristics near to the source. If the distance is small compared to the wavelength, the induction field will predominate. The position with respect to a point source at which these two fields have equal magnitudes is at a theoretical distance of $\lambda/2\pi$. Hence, if 10 m is taken as the measuring distance, all tests below about 5 MHz are in the near field where the magnetic induction signal dominates. With an extended source, such as a train, the near field zone may extend further than the "point source" theory would suggest [3].

In the range of 9 kHz to 150 kHz, traction equipment may be a source of noise at clearly identifiable frequencies. Note that radio signals from outside transmitters can be found, even at these low frequencies, and these should be identified and avoided.

3. Measurement results

The measurement results presented herein were generated during tests carried out on several different test sites and were selected to demonstrate the effect of multiple factors on the levels of ambient electromagnetic disturbance emissions.

3.1. Effect of the position of the tram on ambient noise levels

In order to properly assess ambient noise at the measurement point, it may be necessary to measure ambient levels for different positions of the tram. Since during a stationary test the vehicle is positioned opposite the antennas, disruptive signals coming from external sources may be reflected or shielded by the tram's body. Under certain circumstances, ambient noise might be wrongly interpreted as signals generated by the tested vehicle. The effect of the position of the tram during ambient noise measurements is shown in Fig. 1; it is clearly visible in the higher frequency range of 300 kHz to 2 MHz. The wave representing the ambient noise measurement result for a tram that is in a de-energised mode and positioned within the antenna field is marked in violet, whereas the result for a de-energised tram positioned outside the measurement point. The difference between the results in this frequency range is maximum ca. 15 dB, and higher disturbance levels were recorded for the tram positioned away from the antenna.

A similar result is shown in Fig. 2, where the effect can be clearly seen both in the lower and higher frequency bands under analysis. With regards to a vehicle positioned away from the measurement site, the noise level is higher by a maximum of 20 dB, for the frequency of 1.2 MHz.

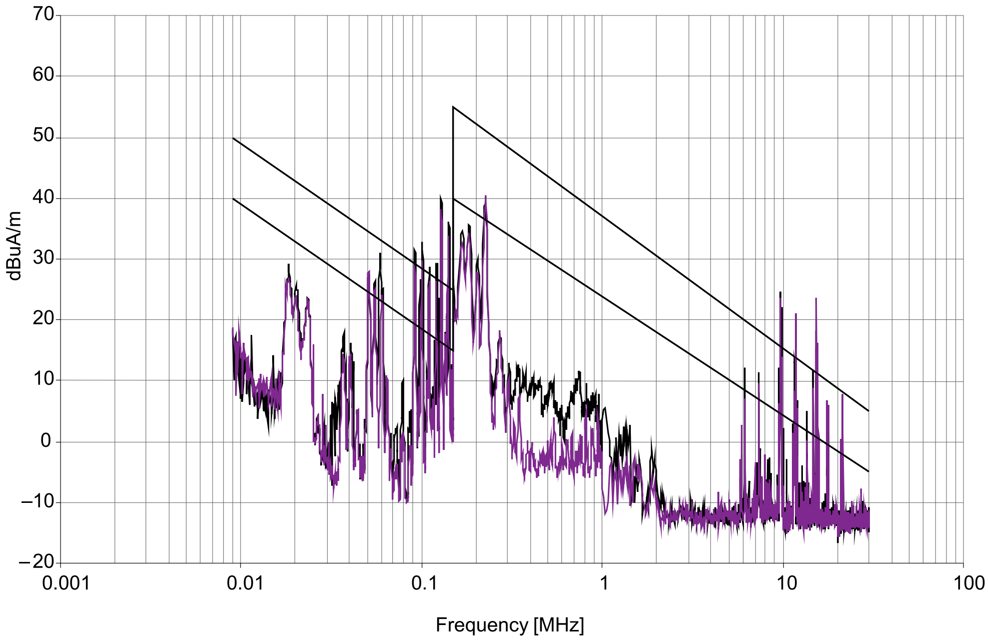

Fig. 1. Ambient electromagnetic disturbances (violet colour – de-energised tram is seen by the antenna, black – the tram is not seen by the antenna)

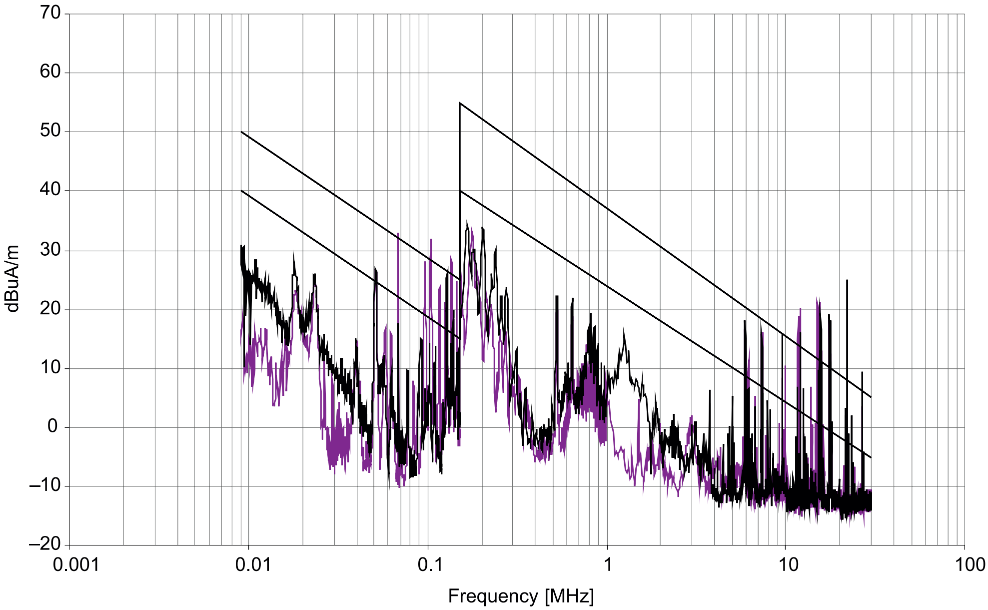

Fig. 2. Ambient electromagnetic disturbances (violet colour – de-energised tram is seen by the antenna, black – the tram is not seen by the antenna)

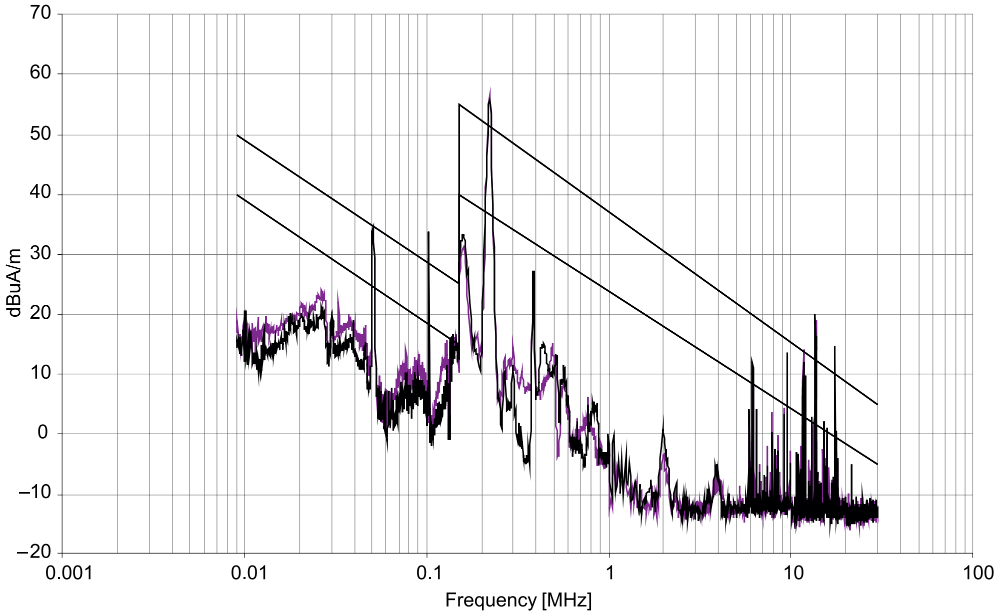

Fig. 3. Ambient electromagnetic disturbances (violet colour – de-energised tram is seen by the antenna, black – the tram is not seen by the antenna)

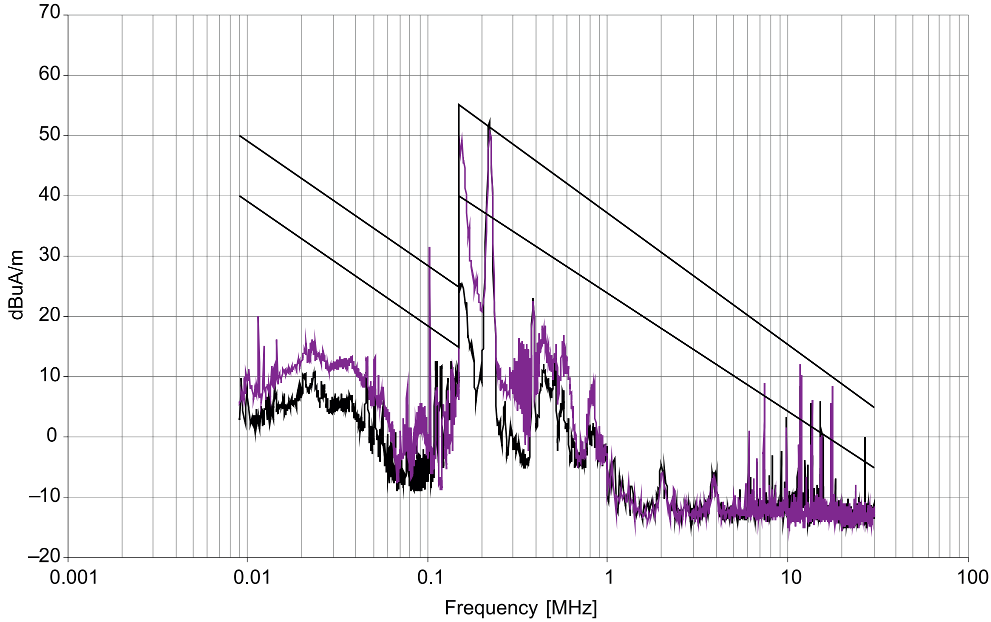

Fig. 4. Ambient electromagnetic disturbances (violet colour – de-energised tram is seen by the antenna, black – the tram is not seen by the antenna)

A converse situation is shown on Fig. 3, which shows the little effect of the position of the vehicle during ambient noise measurements in the lower frequency band of 9–150 kHz. A disturbance level that is higher by ca. 8 dB was found to occur for the vehicle seen by the antenna. Differences can also be seen in the higher frequency band measured.

Similar results, demonstrating the marked effect of the position of the tram during ambient noise measurements in the lower and higher frequency bands, are shown in Fig. 4. It is interesting to note that in the frequency range of 150–200 kHz the ambient noise is increased – a de-energised tram is seen by the antenna, which causes ambient disturbances to increase by up to 25 dB. This may lead to problems in interpreting results obtained during stationary and slow moving tests.

3.2. Effect of other energised trams positioned at a certain distance from the test site

A different situation arises when we want to examine the effect, on the level of measured noise coming from the areas surrounding the test site, produced by other vehicles supplied on the same catenary as the tested tram. Under certain circumstances, it is possible to identify such vehicles and de-energise them so that a relatively low ambient noise level can be obtained.

Figure 5 shows the results of ambient noise measurements (tram being tested is de-energised) when the other vehicles are energised. The red graph represents a situation where two remote vehicles are energised, the blue graph – one external vehicle is energised, and black – both trans are de-energised. The worst case obviously obtains for two vehicles, where ambient noise can increase by a maximum of 32 dB for the frequency of 15 kHz. This is yet another situation when the assessment of the vehicle under test, both in a stationary and slow-moving test, can be a difficult task.

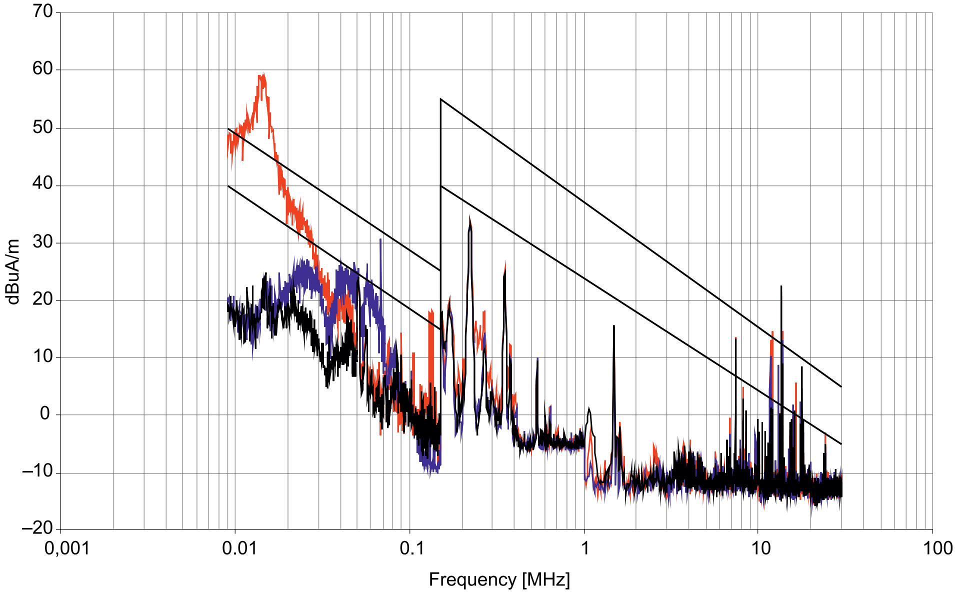

Fig. 5. Ambient electromagnetic disturbances (red graph – 2 energised trams, blue – 1 energised tram, black – no energised trams)

3.3. Effect of power supply system feeding the catenary

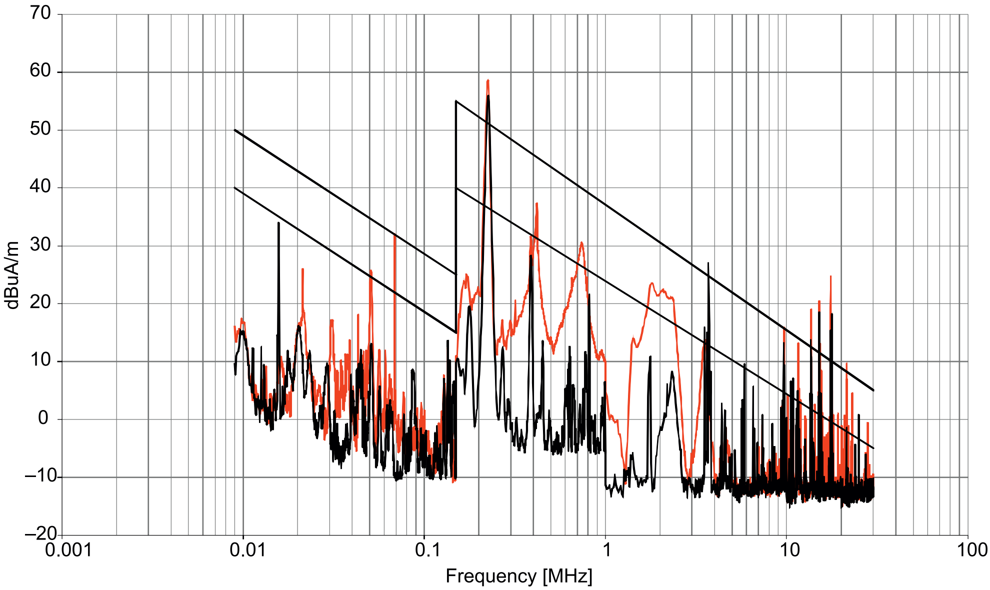

Fig. 6. Ambient electromagnetic disturbances (red – effect of disturbances generated by the supply system, black – filtered power supply)

In addition to disturbances generated by other vehicles, increased emissions may be due to the operation of the system feeding the catenary. In the situation shown in Fig. 6, the dominant source of electromagnetic disturbance emissions is a substation based on a controlled inverter. The use of inverter control makes it easy to adjust output voltage, but the disadvantage is that disturbances in the 400–2.5 MHz range are generated. The red graph represents the results obtained for an inverter without RFI filters, whereas the black graph represents the emission levels after additional EMC filtering circuits were installed.

3.4. Effect of input circuits of tram under test

A separate case observed during the tram radiated disturbance emission measurements was the effect that its input circuits had on the emission levels. The input circuits in question were high frequency filtering circuits based on inductive and capacitive elements. Fig. 7 shows ambient noise measurement results for a de-energised vehicle seen by the antenna.

The black graph represents a situation where there is no pantograph-catenary contact, while the green graph represents results for the pantograph touching the catenary.

The obtained disturbance result suggests that the impedance of the input circuits, connected to the overhead line in the second case, leads to an increase in the high-frequency currents in the catenary, which, at the same time, increases the radiated disturbance emissions. A

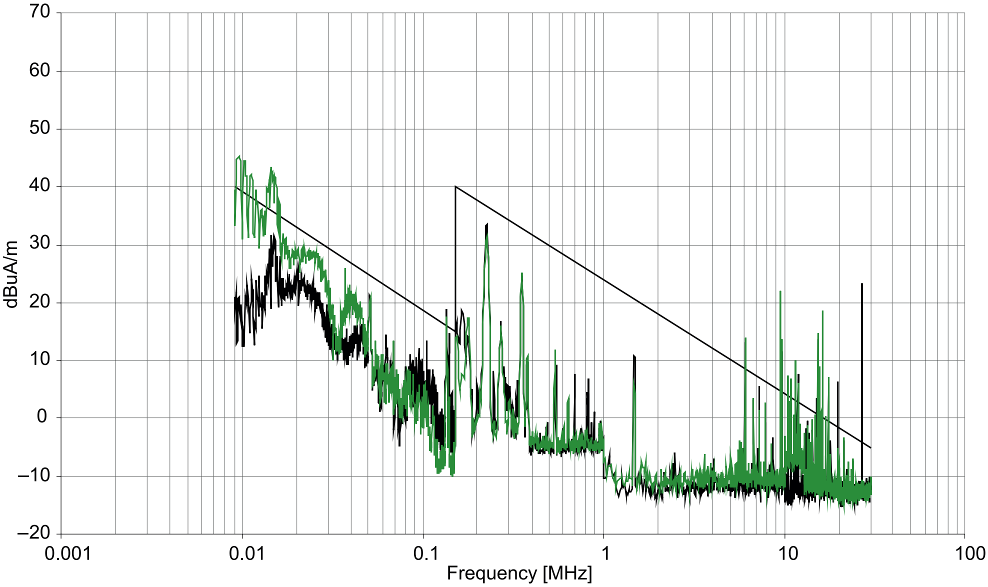

Fig. 7. Ambient electromagnetic disturbances (green – a de-energised tram with its pantograph raised, black – a tram with its pantograph lowered)

marked increase in emissions can be seen in the 9–50 kHz range, reaching as much as 25 dB. Such a situation can be interpreted as an increase in the ambient emission levels because the vehicle inverter circuits are de-energised; however, when assessing the vehicle, this aspect should not be left out.

4. Conclusions

The examples discussed in the article illustrate factors that contribute to ambient electromagnetic emissions at open tram test sites. Identifying the existing ambient emission sources and determining the effect of their position vis-a-vis the tested vehicle may make it easier to properly assess the obtained results. If the measurement results are not properly interpreted, a conclusion may be drawn that increased radiated electromagnetic disturbances are generated by the tested tram. In extreme cases, if the emissions measured exceed permissible levels, the test report may indicate that the tested tram fails to meet the requirements of the applicable standard. The selection of measurement results discussed shows that a detailed analysis of the measured ambient noise allows for a correct assessment of radiated disturbances from the tested tram.

References

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