Monika E. SZAFRAŃSKA

Wroclaw University of Science and Technology, Faculty of Electronics

doi:10.15199/48.2017.12.11

Overview of electromagnetic waves propagation in tunnels – detection of electromagnetic disturbances source

***Abstract**. The paper includes preliminary considerations on the possibility of correlating results of radiation disturbances emissions' measurements from sources of disturbances present in tunnels (especially of underground mines). On the one hand, the proposed approach is to detect sources of interference by correlating the measurements results with the simulation results. On the other hand, a correction factor for the initial evaluation of devices generating disturbances in the tunnels is to be derived.*

***Streszczenie.** W niniejszym artykule zawarte zostały wstępne rozważania nad możliwością korelacji wyników pomiarów emisji zaburzeń promieniowanych od źródeł zaburzeń pracujących w tunelach (w szczególności w tunelach podziemnych kopalń). Zawarto propozycje podejścia do tematu poszukiwań źródeł zakłóceń poprzez korelowanie wyników pomiarów z wynikami symulacji oraz poprzez wyznaczanie współczynnika pozwalającego na wstępne ocenianie urządzeń generujących zaburzenia a pracujących w tunelach. (**Przegląd sposobu propagacji fal elektromagnetycznych w tunelach – wykrywanie źródła zakłóceń elektromagnetycznych**).*

Keywords: propagation; EMC tests; correction factor; test set-up
Słowa kluczowe: propagacja; badania EMC; współczynnik korekcyjny; stanowisko pomiarowe

Introduction

Issues related to the propagation of radio waves in tunnels are of high importance in literature studies and in theoretical considerations. Particular emphasis is placed on issues related to the propagation of electromagnetic waves directly related to communication systems. Whereas, much less emphasis is put on the issues related to the propagation of other electromagnetic waves, e.g. generated by disturbance sources that may become the sources of interference for other equipment working in tunnels.

Therefore, this paper focuses on issues related to the propagation in tunnels. Although, the issues related to propagation in tunnels have been observed and described theoretically by many authors, in this paper they are presented together with the practical aspect of propagation of disturbances that may cause interference in other machines' work.

The author, for many years has been involved in electromagnetic compatibility tests of mining machinery for which the typical target environment are underground tunnels. Such machinery generates very complex radiated disturbances, especially in the frequency range from 30 MHz to 200 MHz. These disturbances can propagate over considerable distance and cause malfunction of other machinery by interfering with its normal operation. Therefore, it is necessary not only to look at the source of the disturbances but also to analyse the propagation environment specifics.

Thus, the aim of this paper is to demonstrate the relationship between the generation of electromagnetic waves in tunnels and interference with other equipment operation. Moreover, the paper highlights important components that should be considered when analysing the propagation of the disturbances in tunnels in the considered frequency ranges, as well as the parameters related to the tunnel geometry and its equipment. It also presents results of mining equipment tests with a reference to the current requirements for the allowed and acceptable electromagnetic disturbances emissions in the given environment and the possible interactions of excessive disturbances with other equipment that can also work in the tunnels.

General considerations of propagation in tunnels

When considering propagation in mines one should be aware of the possible waveguides that can form along the mine corridors or in tunnels. Equally important issue is sudden and very rapid attenuation of signals. Most of the previous studies on propagation issues [1 ÷14] were mainly associated with frequencies much higher than those deemed to be significant from the point of view of harmful phenomena, for example frequency range of such disturbance sources as arcing between the pantograph and the catenary, inverters and LED lights.

Fig. 1. Underground tunnel of the copper mine

Moreover, to properly describe the phenomenon concerned, it is necessary to identify potential routes of disturbance propagation. As it was already mentioned, in this case we are dealing with the two main modes of the propagation of disturbances that have their source at the pantograph- catenary contact point:

- conducted disturbances – disturbance currents in power lines,
- radiated disturbances – generated in the near field around the source.

Both conducted and radiated disturbances, due to non-linearity of the source and due to the uniqueness of their occurrence, are particularly dangerous for devices operating in the close vicinity of the disturbances source.

While in the case of radiated disturbances we are considering mainly the effects occurring in the near field and at the distances of up to 20 meters from the source, in the case of conducted disturbances we usually have to deal with the transfer of signals at the distances that are much bigger. The reason for that is the fact that power and signal lines run in the mines or in other tunnels for considerable distances, thus creating great route of propagation for the conducted disturbances.

During many measurements carried out by research team of the EMC Department of National Institute of Telecommunications (NIT) and its EMC Testing Laboratory, a strong dependence was observed between disturbance fields occurring in the near field and disturbance currents generated by the presence of large objects. Therefore, when considering and testing this phenomenon, the main aspect that must be taken into consideration is the correlation between the disturbance current in the catenary and the field strength present in the close vicinity of the eq.

Practical aspect of propagation in tunnel's research

The author wishes to introduce the essence of radio wave propagation discussing it not only from the point of view of the attenuation and amplification of a signal at a certain distance, but also from the point of view of the exemplary practical application – detection of disturbance sources. Research works on propagation in tunnels, although well known, are mainly considering usability of the propagating waves for wireless communications. Most research works focus on defining propagation coefficients and describing phenomena on the frequency ranges where for example the trunking systems work (e.g. above 400 MHz). Also well-known are the propagation models and studies covering the frequency ranges used for the communication purposes.

Fig. 2. Traction locomotive, loop antenna for magnetic field measurements in front

However, the typical target environment for the mentioned machinery are the underground tunnels. These machines do generate significant radiated electromagnetic disturbances, but especially in the frequency range from 30 MHz to 200 MHz. These disturbances are capable of being spread over considerable distances and can cause malfunction of other machinery and can interfere with their normal operation. This article is intended to demonstrate the relationship between the generation of electromagnetic waves in tunnels and interference occurring in the equipment being the victim of the disturbances that propagate in the tunnels. Some exemplary mining equipment tests results are presented and referenced to the current requirements for the allowed electromagnetic disturbances emissions to the environment and the possible interactions of such disturbances with the equipment working in tunnels.

This new approach, based on finding the correlations between the potential sources of disturbances and the levels of emissions generated by them in mine (tunnels) conditions is also very important in difficult, disputable situations in which the interference with the equipment located close to the sought source of the disturbances occurs.

In many mines, especially after the introduction of highly advanced automated mining processes, there have been problems with accidental (as originally thought) switching or overdriving. This is reflected extensively in NIT works.

Since 2006, the NIT team has conducted numerous research works subjected to verify the electromagnetic environment of mines – some findings of these works can be found in [15] and [16]. During the author's analysis of these research works one issue has emerged – even in the case of mining equipment meet the requirements of EMC [17] some immunity problems are occurring. This led to the hypothesis, that the electromagnetic environment of the underground mine differs significantly from the on surface electromagnetic environment. Hence, the NIT team research on this subject might be a proof of that of a paramount importance.

Large devices, including the mining ones are tested (if it is possible due to their dimensions) on the ground and the levels of disturbance generated by them are referred to the Open Area Test Site (OATS). As it was demonstrated by the practice, in particular for devices that have relatively low reserve in recorded disturbances when compared to those limits, these devices frequently become the sources of significant disturbances in the environmental and physical conditions of the mine (read: while working in the tunnel). Considering the derivation of correction factors that could allow for the comparison of the on-site (in situ), made in the tunnel measurements results to the OATS radiated emission levels, special attention should also be given to such types of equipment for which the on surface tests cannot take place (due to the size or the fact that the machine is not being built / assembled until underground).

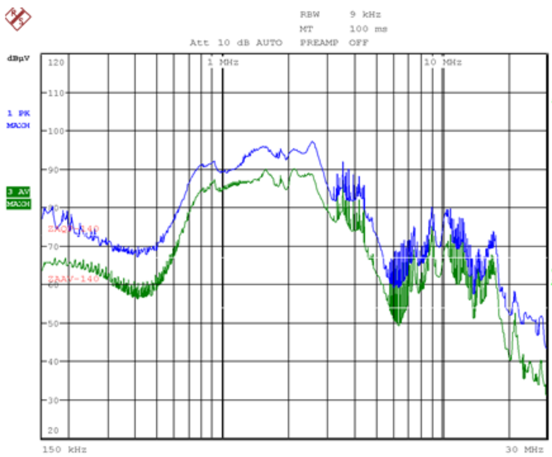

Fig. 3. Example of conducted disturbances from the locomotive, measured in catenary.

In Fig. 3 one example of such problematic sources of the disturbances can be found. which On the one hand these sources undoubtedly cause disturbances, while on the other hand they are rarely EMC tested on the surface. Moreover, there is very little to say about their emission characteristics as well as their work as the disturbance sources.

The perfect example that could be considered as the source of disturbances generated in mine tunnels is mining traction locomotive. Some results of the disturbances observed and recorded by the team from the National Institute of Telecommunications, EMC Department during the tests of locomotive are shown in Fig. 3.

This example (see Fig. 3) shows that the level of disturbances exceeds the typical levels of disturbance almost 40 dB from industrial equipment (in this frequency range limit is equal 73 dBμV for QP detector and 60 dBμV for average detector [18]). That situation means the disturbance voltage is almost 100 times higher than the highest typical RF voltage recorded in industrial environment [18]. That kind of object generating such significant disturbances may cause the incorrect operation of devices in the vicinity and also devices powered from the same transformer.

The knowledge and experience gained during those measurements indicate that when describing the electromagnetic environment the main thing is to correctly identify and appropriately determine the direction of disturbances propagation in this environment. What is more, it is particularly important in the case of the radiated disturbances, because the direction of the disturbance propagation, when we consider the physical characteristics of the tunnels, determines the range of these disturbances propagation. Environmental studies in underground mines are particularly difficult because of the limited space, the long, narrow and low corridors and the accumulation of a large amount of electrical equipment on a small area, while most of this equipment is interconnected through the common supply network and very complicated and widely distributed network of signal lines. It should also be noted that the mine is a very specific object, where many cables run in the narrow corridors in parallel over long distances, including high and medium voltage cables, signal cables as well as traction cables. One of the effects of this is the induction of the disturbances from one line to another.

Particularly significant difference between mine environment and terrestrial environment can be observed in terms of the emissions of radiated and conducted disturbances. In the case of underground mining, the conducted disturbances are much more important than the radiated disturbances. In terrestrial environments radiated disturbances in the far field are mostly taken into account, whereas in the case of underground mines environment radiated disturbances in the near-field become more important, for example the ones that are generated by traction locomotives. These disturbances may affect the machines located near the locomotive tracks, but they can also propagate to greater distances as current disturbances induced on the catenary and the signal lines guided along the walls of the corridor and, above all, by penetration into the overhead line. Among other radiated disturbances that also occur in these conditions there are some radiated signals associated with the desired emissions associated with communication or control machines, but those are, however, much less important.

The main range of the frequency impact of the radiated disturbances usually coming from this type of device is up to about 200 MHz (300 MHz maximum).In most cases the observed effects of disturbances in the frequency range of 30 to 200 MHz are secondary effects, The sources generating them are operating/generating disturbances in the frequency bands up to a single MHz. Well known sources of similar disturbances observed on the surface are the inverters (increasingly used), in case of which the radiated disturbances are generated mainly due to the effects of short switching times (clocking).

Returning to the example presented in Fig. 3. – the measurements which results are presented here were performed on catenary using the current probe. The disturbances that were measured there were quite significant and can easily exceed the allowed levels for the industrial environment. It must also be remembered that these disturbances can be propagated in catenary for some considerable distance.

Test set-up

As it was previously mentioned, a significant issue with disturbance source detection is the attempt to determine a correction factor that can allow to correlate the results obtained during in tunnel testing so that it can be compared to the requirements that were set out in the EMC standards for the OATS measurements. It should be stressed out here that in analysing the spread of tunnel disturbances in the observed frequency ranges, very close attention should also be paid to the issues related to the geometry of the tunnel and the equipment that is present in the tunnel.

Fig. 4. Railway shelter

For the preliminary work on the correlation between the results of emission measurements of disturbances obtained on OATS and the results obtained in the tunnel, as a representative generalized case, the tunnel of the German (WW II) railway shelter located near Konewka village was used.

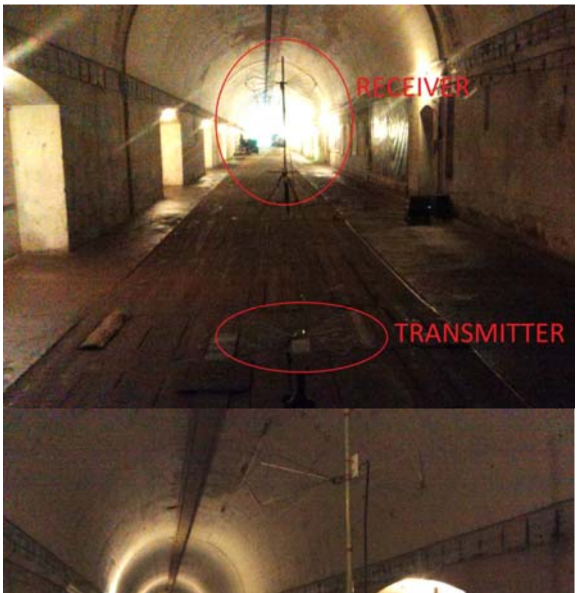

Fig 5. Test set-up inside the tunnel

In the tunnel, in around 150 – 200 meters distance from the entry to the tunnel, receiving antenna (allowing 1 – 3,5 m height scanning) and transmitting antenna (positioned 80 cm over ground level, with comb generator attached) were placed. Fig. 5 presents the pictures from the tests site.

The tests were carried out for 3 m and 10 m measuring distances – the typical ones also for the OATS applications. The test results were noted and the correlation with OATS measurements of the same comb generator were made.

Initial results show the possibility of the introduction of required correction factor, but more thorough test measurements and numerical simulations are needed.

In the next stage of this research the author plans to prepare the numerical model that will allow to simulate the results of the field strength distribution in the tunnel, which in turn will allow her to derive the correction factors for different physical parameters of the tunnels.

Further research on the subject that was mentioned in the section is also planned. It refers to tunnels' further cabling along the tunnel as an additional propagation path. It should be included in the research as they can significantly influence the derived correction factor, especially in the frequency range that is considered here.

Conclusion

The author takes preliminary considerations on the possibility of correlating the results of measurements of radiation disturbances emission from the sources of disturbances working in tunnels. The Proposed approach was the searching for the sources of interference topic by correlating the measurements results with the simulation results and by the derivation of a correction factor for the initial evaluation of devices generating disturbances in the tunnels.

This study is the introduction and basis for the preparation of a mathematical model that will be able to be adapted to the physical parameters of the tunnels for which the need for a correction factor will be determined. These works will be further developed accordingly to allow the model validation and to show the reproducibility of the simulation results in measurements based on radiation emission test methods. Further research is still needed to fully illustrate the correlation method proposed here and it will be the significant part of the author's research.

Acknowledgment

The author would like to thank the managers of "Trasa turystyczna »Bunkier w Konewce«" for the opportunity to perform the tests inside the railway shelter tunnel.

***Author**: mgr inż. Monika E. Szafrańska, Politechnika Wrocławska, Wydział Elektroniki, ul. Janiszewskiego 11/17, 50-372 Wrocław, e-mail: monika.szafranska@pwr.edu.pl*

REFERENCES

[1] Worek C., Szczurkowski M., Kałuski M., Zagadnienia propagacji fal radiowych w podziemnych zakładach górniczych w aspekcie gospodarki widmem radiowym, *Wybrane obszary infrastruktury systemowej kopalń podziemnych*, EMAG 2012, str. 223-229

[2] Bieda B., Brodiuk A., Zieliński R., Propagacja fali elektromagnetycznej w środowisku wyrobiska kopalnianego, *Przegląd Telekomunikacyjny Wiadomości Telekomunikacyjne*, 2008, nr 4, s. 505-508

[3] Didascalou D., Maurer J., Wiesbeck W., Subway Tunnel Guided Electromagnetic Wave Propagation at Mobile Communications Frequencies, *IEEE Transactions On Antennas and Propagation*, November 2001, vol. 49, no. 11,

[4] Liénard M., Degauque P., Natural Wave Propagation in Mine Environments, *IEEE Transactions on Antennas and Propagation*, September 2000, vol. 48, no. 9, pp. 1326-1339

[5] Delogne P., EM Propagation in Tunnels, *IEEE Transactions on Antennas and Propagation*, March 1991, vol. 39, no. 3, pp. 401-406

[6] Didascalou D., Maurer J., Wiesbeck W., Subway Tunnel Guided Electromagnetic Wave Propagation at Mobile Communications Frequencies, *IEEE Transactions On Antennas and Propagation*, November 2001, vol. 49, no. 11, pp. 15901596

[7] Wang S., Radio Wave Attenuation Character in the Confined Environments of Rectangular Mine Tunnel, Modern Applied Science, 2010, vol. 4, no. 2, pp. 65-70

[8] Zhang Y. P., Jiang Z. R., Ng T. S., Sheng J. H., Measurements of the Propagation of UHF Radio Waves on an Underground Railway Train, *IEEE Transactions on Vehicular Technology*, July 2000, vol. 49, no. 4, pp. 13421347

[9] Mariage Ph., Liénard M., Degauque P., Theoretical and Experimental Approach of Propagation of High Frequency Waves in Road Tunnels, *IEEE Transactions on Antennas and Propagation*, January 1994, vol. 42, no. 1, pp. 75-81

[10] Zhang Y. P., Zheng G. X., Sheng J. H., Radio Propagation at 900 MHz in Underground Coal Mines, *IEEE Transactions on Antennas and Propagation*, May 2001, vol. 49, no. 5, pp. 757-762

[11] Lienard M., Degauque P. Laly P., Communication and Distance Measurement in Subway Tunnels using Natural Propagation, *Fifth IEEE International Caracas Conference on Devices, Circuits and Systems*, November 2004, pp. 240-243

[12] Cerasoli C., RF Propagation in Tunnel Environments, *MILCOM 2004, IEEE Military Communications Conference*, pp. 363-369

[13] Wang T.,Yang Ch., Simulations and Measurements of Wave Propagations in Curved Road Tunnels for Signals From GSM Base Stations, *IEEE Transactions on Antennas and Propagation*, September 2006, vol. 54, no. 9, pp. 2577-2584

[14] H. Kenneth Sacks, Robert L. Chufo, "Medium-Frequency Propagation in Coal Mines"

[15] Kałuski M., Michalak M., Pietranik M., Skrzypek K., Szafrańska M., Potrzeby zmian w normalizacji badań EMC w środowiskach specjalnych, *Electrical Review (Przegląd Elektrotechniczny)*, Feb. 2012, no. 2, pp. 79-81

[16] Kałuski M., Michalak M., Pietranik M., Skrzypek K., Szafrańska M., Disturbances in Industrial Power Networks, *Electrical Review (Przegląd Elektrotechniczny)*, September 2012, no. 9b, pp. 298-300

[17] DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility

[18] IEC 61000-6-4: Emission standard for industrial environments