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Susceptibility of 4G communications in railway EM environment

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Abstract

The railway sector has continuously offered new services to be attractive and face the competition of the other means of transports. In this context, providing access to the Internet on board trains could permit the passengers to optimize their time spent in the train.
In France, the main railway operator aims to offer internet access in 90% of its trains by 2020. The current proposed solution is based on 4G communications, e.g., long-term evolution (LTE) between the train and the ground, and Wi-Fi inside the coaches.
The LTE reception on the train would be ensured by an antenna on the train roof. However, the railway electromagnetic (EM) interferences produced by the contact losses between catenary and pantograph can affect the reception of the LTE signal. In this context, this paper presents a susceptibility analysis of the LTE communication in the presence of EM interferences representative of those observed on board trains.

1. Introduction

The railway sector has to continuously evolve and provide new services to be attractive and face the competition of the other transport means.
In this context, the main French railway operator is currently developing solutions to guarantee internet access in 90% of its trains by 2020. Indeed, access to the Internet on board trains could permit the passengers to optimize the time spent in the train.

Currently, 4G communications, e.g., long-term evolution (LTE), provide individual access to the Internet. However, on board train, it does not offer a very efficient connection to the Internet, because of the large number of passengers who can request for an Internet connection at the same time.

The current proposed and studied solution is based on a specific LTE communication link between the train and the ground, and the Wi-Fi inside the coaches, with one access point per car. An LTE antenna placed at the top of the train car will ensure the LTE communications between the train and the ground.

In this context, a previous study compared the susceptibility of 2G communications, currently used in railway for ground to train communications, and 4G communications when confronted with EM interferences present in Railways [1]. Indeed, the communication signal received by the LTE antenna placed on the train roof could be affecte by the EM interferences produced by the contact losses between catenary and pantograph.

However, the comparison with 2G communications is not really obvious because 4G communications can adopt very variable configurations. In particular, the bandwidth channel and the modulation can vary.
Therefore, this paper studies the susceptibility of 4G communications for different configurations in the presence of transient EM interferences, representative of those produced by the catenary-pantograph contact.

The following section will give a brief description of the LTE communication system. Then, the test bench and test configuration will be described in details. The model employed to represent the EM interferences present on board trains, will be defined and justified. Finally, the last section presents and discusses the impact of the EM interferences on communication quality.

2. The LTE communication system

Long Term Evolution (LTE) is a radio communication system identified as a 4G communication technology. It is a cellular communication system based on a network of base stations which are called eNodeB. LTE uses orthogonal frequency-division multiplexing (OFDM) as a modulation technique. OFDM permits you to transmit data on multiple frequencies, which are evenly distributed within the allocated frequency band.

LTE works with adaptable bandwidth channels going from 1.4 MHz to 20 MHz, allowing peak downloading rates at 300 Mbit/s. LTE supports both Frequency Division Duplexing (FDD) by allowing two different channels for uplink and downlink, and Time Division Duplexing where uplink and downlink share the same frequency channel. In this study, we used the FDD mode.

The LTE frequency bands can be used simultaneously by different users. Thus, these bands are divided into sub-carriers which are dynamically allocated to users depending on their needs. In order to guarantee this dynamic allocation, LTE splits the band in the time and frequency domain into elementary elements called resource elements (RE). Each RE occupies 15 kHz (one sub-carrier) and 66.7µs. These resource elements are regrouped into Resource blocks (RB), composed of 12 sub-carriers (180 kHz) and 7 OFDM symbols of 66.7µs, e.g., 0.5ms. Two consecutive resource blocks constitute a 1ms sub-frame [2].

OFDM encoding technique is used for its high robustness. However, the transient EM interferences present on board train are very specific to the railway environment. The real robustness of LTE communications when faced with such interferences needs to be studied.

3. Test configuration

To test the robustness of 4G communications, we established communication between an eNodeB emulator and an LTE dongle. The tests were performed in conducted mode using combiners between the base and mobile stations in order to introduce transient EM interferences on the uplink as shown on the schematic diagram in Figure 1.

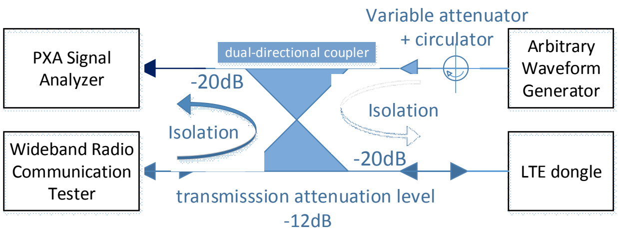

Figure 1. Schematic diagram for a LTE communication in the presence of EM interferences.

A CMW500 wide band communication tester was employed to emulate the LTE eNodeB. A LTE dongle connected to a computer was employed as a mobile station. An arbitrary waveform generator (AWG) was used to generate EM interferences, the model of which was previously defined with Matlab. Figure 2 represents the test bench.

Moreover, a variable attenuator was connected at the output of the AWG to vary the Interference to communication Signal Ratio (ISR).
The ISR is the ratio of the maximum interference signal power minus the attenuation to the maximum Uplink signal power. To calculate the ISR, the interference signal and uplink signal powers are measured at the CMW500 input by means of a spectrum analyzer with a 15 kHz resolution bandwidth, corresponding to the frequency width of the sub-carriers.

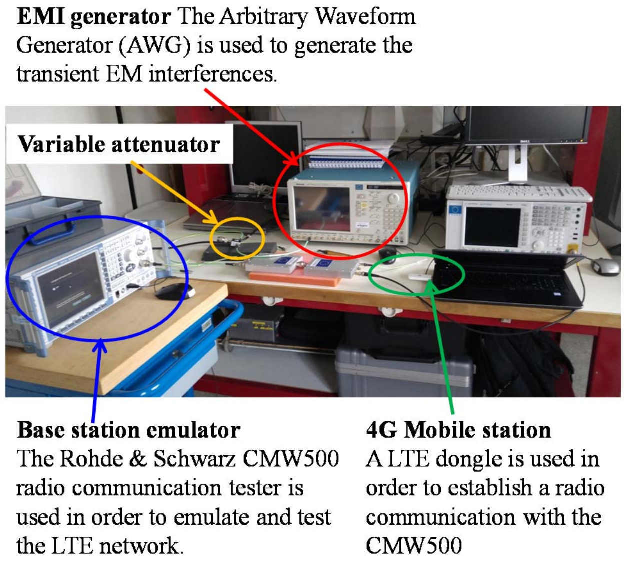

Figure 2. LTE communications test bench in the presence of EM interferences.

LTE communications between train and ground can be ensured by using two frequency bands, one dedicated to the uplink between the train and the ground base station and another one dedicated to the downlink from the ground base station to the train. Several frequency bands can be employed by the LTE. In these tests, the band 8 was employed corresponding to 880-915 MHz for the uplink and 925-960 MHz for the downlink. This band was employed because the frequencies are quasi similar to those dedicated to the GSM for Railway (GSM-R) which makes it possible to perform comparisons between the susceptibility of both communication systems to railway EM interferences.
Moreover, the EM interference characterization performed in previous work on board trains was carried out with GSM-R antennas covering the 900 MHz frequency range. Then, working in band 8, this previous work can be exploited to define the EM interference model.

Moreover a large number of parameters can vary in LTE communications. In this paper, the susceptibility analysis is studied according to the channel bandwidth of the communication.
The power and the modulation scheme were fixed and the quality of the reception signal were studied in the presence of interferences for different communication channel bandwidths (1.4MHz - 3MHz - 5MHz - 10MHz) [3].
The communication signal power is defined by the Energy Per Resource Element (EPRE) that was put at -50dBm/15kHz and a QPSK modulation scheme was chosen.

4. Electromagnetic Interference signal

The considered EM interferences are transient EM disturbances produced by contact losses between the catenary and the pantograph. These wide band interferences cover very high frequencies and can be receive by 2G and 4G antennas, which are on the train roof [4].

The model of the transient interference signal is based on previous works involving measurements on board trains and statistical analyses [4]. These previous works permitted us to extract a representative model but also demonstrated that the time characteristics can vary between the successive transients.

Moreover, considering communications between an eNodeB and a mobile station on board train, only the reception signal at the train level can be disturbed by the EM interferences produced by catenary-pantograph contact losses. So, for these tests, an interference model which respects the time characteristics of the transient interferences produced on board trains but which only affects the frequency band of one directional link must be applied.
A double exponential signal was then employed, modulated with a sinus in order to focus the interference signal over the frequency channel of only one communication link. The corresponding equation is the following:

$$S(t) = A \times (e^{-\frac{1}{D}t} - e^{-\frac{1}{RT}t}) \times u(t) \times \sin(2\pi F t) \quad (1)$$

Where A = 1 V, D = 40 ns, RT = 2 ns, F = 897.5 MHz is the central frequency of the uplink channel and u is the unit step function.

Knowing that in the laboratory, the quality of the reception signal can only be measured on the signal received by the CMW500 radio communication tester, the interference signal model was defined to affect only the frequency band of the signal sent by the LTE dongle and received by the radio communication tester. Then, in Eq. (1), F = 897.5 MHz corresponds to the central frequency of the signal sent by the LTE dongle. The time and frequency representations of the interference models obtained with Matlab are presented in Figures 3 and 4.

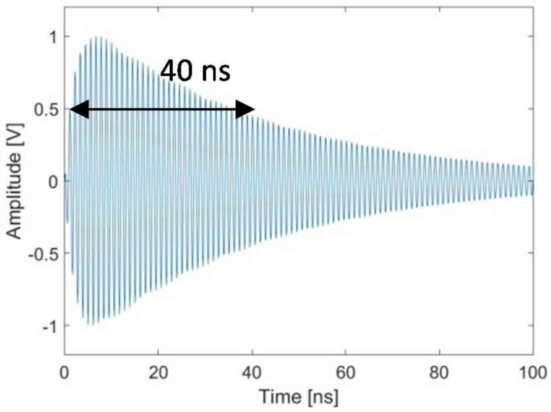

Figure 3. Representation of the EM interference signal model in time domain.

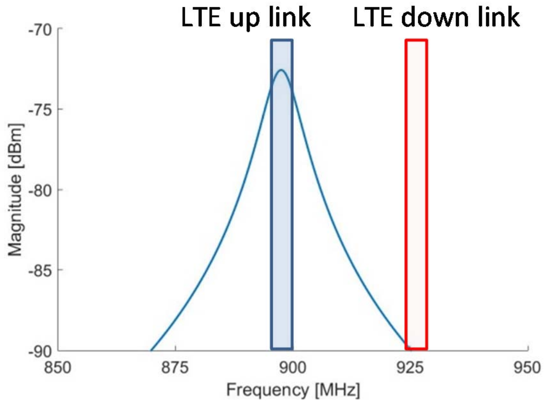

Figure 4. Representation of the EM interference signal model in frequency domain.

The interference signal was repeated with a 100 µs time interval between two successive occurrences. In reality, the analyses of the transient EM interference produced on the trains showed that the intervals between successive interferences can vary significantly [4]. However, for this study, a constant value of time interval was considered and a 100 µs interval was applied, which is superior to the OFDM symbol duration (66.7 µs).

5. Results

A basic measurement in order to analyze the physical layer is the Error Vector Magnitude (EVM) measurement. The EVM_{RMS} is the difference between the ideal and the measured waveforms, in the presence of interferences, for an allocated Resource Block (RB) [5].

The EVM_{RMS} measurement results as a function of the ISR and for different channel frequency bandwidths are grouped in figure 5.

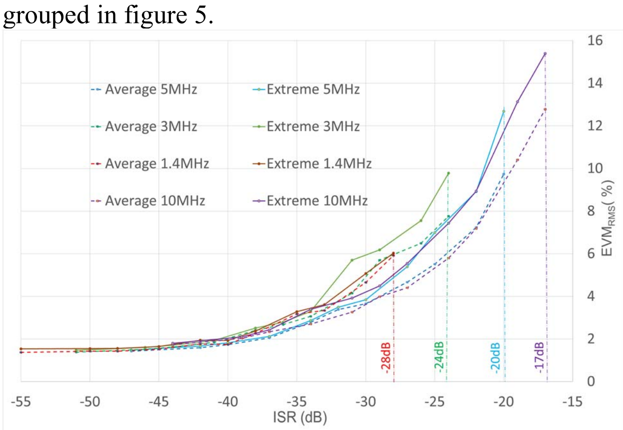

Figure 5. EVM as a function of the ISR, for a QPSK modulation.

The EVM measurements (RMS Average and RMS Extreme values) show that for an ISR inferior to -40 dB, the EVM is constant and has the same value (EVM≈1.5%) whatever the LTE channel bandwidth.
For an ISR greater than -40 dB, the EVM depends on the channel bandwidth. The larger the bandwidth, the smaller

the EVM: for an ISR of -28dB, the EVM is 4% for 5 MHz and 10 MHz and 6% for 1.4 MHz and 3 MHz.
Moreover, it is observed that the communication can be completely lost for different values of ISR according to the channel bandwidth. For example, with a 1.4 MHz channel bandwidth, the communication is lost for a -28 dB ISR while with a 10 MHz bandwidth, the communication is robust up to an ISR of -17 dB.
These results indicate that communication over a wider channel bandwidth can stand a higher EVM value. However, the standard ETSI [6] mentions that the maximal acceptable EVM for QPSK modulation is 17.5% and it is noticed that the communication is lost for EVM value significantly lower than this 17.5 % limit. It is expected that the interference impacts other quality parameters which involve a loss of communication. To complete this analysis, we then need simultaneously analyze several quality parameters.

6. Conclusion

This paper presents a method to analyze LTE communication facing transient EM interferences produced by catenary-pantograph sparks.
A test bench was implemented and the results show that the susceptibility of LTE communication when faced with EM interferences present on board trains is not constant and depends on the LTE communication channel bandwidth. It has been observed that for similar ISRs, larger channel bandwidths give lower EVM levels.
Secondly, the interruption of the communication occurs for different ISRs and at different EVM levels according to the LTE channel bandwidths. Indeed, for the more narrow bandwidths, the loss of communication is produced for an EVM value significantly inferior to the limit indicated in the ETSI standards [6]. It is then expected that the applied EM interference affects other quality parameters which induces the interruption of the communication.

Then, to further analyze how such railway interferences impact LTE communication performances, it will be necessary to simultaneously analyze several quality parameters. Other parameters such as Reference Signal Receive Power (RSRP), Signal to Noise Ratio (SINR) and Reference Signal Receive Quality (RSRQ) will be studied to analyze the susceptibility of 4G communications.

7. Acknowledgements

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8. References

1. M. R. Kousri, V. Deniau, J. Rioult, G. Romero, E. P. Simon, Comparative Study of Transient Disturbances Impact on 2G and 4G Telecommunication Systems in a Railway Context, URSI GASS 2017, Montreal, 19-27 august 2017
2. ETSI, “LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation,” 3GPP TS 36.211 version 10.0.0 Release 10, 2011.
3. ETSI, LTE; Evolved Universal Terrestrial Radio Access (E-UTRA);User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Conformance testing (3GPP TS 36.521-1 version 8.3.1 Release 8)
4. N. Ben Slimen, V. Deniau, J. Rioult, S. Dudoyer and S. Baranowski, "Statistical Characterisation of the EM Interferences Acting on the Communications Between Trains and Control Centers", The European Physical Journal – Applied Physics, Published online: 22 Sept. 2009.
5. ETSI, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception" 3GPP TS 36.104 (version 8.13.0 Release 8)
6. ETSI, LTE ; Evolved Universal Terrestrial Radio Access (E-UTRA) ; User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 8.13.0 Release 8)