3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

A test methodology to assess the susceptibility of LTE communications in a railway electromagnetic environment

Nathan Chopinet [(1)], Virginie Deniau*[(1)], Eric Pierre Simon [(2)], Artur Nogueira de São José[(3)], Jonathan Villain[(1)]
(1) Univ. Gustave Eiffel, IFSTTAR, Univ Lille, F-59650 Villeneuve d'Ascq, France
(2) Univ. Lille, CNRS, UMR 8520-IEMN-Institut d'Electronique de Microélectronique et de Nanotechnologie, F-59000 Lille, France
(3) Univ. Lille, CNRS, USR 3380 - IRCICA - Institut de Recherche sur les Composants logiciels et matériels pour l'Information et la Communication Avancée, F-59000 Lille, France

Abstract

The LTE communication protocol is more and more employed in the railway domain. Indeed, the LTE throughput enables railway companies to offer Wi-Fi connections to their customers inside the trains. LTE is also used in innovation projects such as remote train control and autonomous trains. However, there is no standard laboratory procedure to test this type of communication system face to electromagnetic interference present in the railway environment. In this context, we investigate the LTE susceptibility to transient electromagnetic interference sequences produced by the catenary pantograph contact. We proposed a test bench and process and we analysed the repeatability of susceptibility test performed on LTE communications.

1 Introduction

Currently, the Long Term Evolution (LTE) communication protocol is employed in two different railway applications. Firstly, the LTE allows providing Wi-Fi internet connections on board trains. Secondly, LTE is employed in research projects about trains remote driving.

The trains remote driving is a perspective envisaged by the French railway company SNCF through projects as Tc-Rail [1] to fit in a future technology leadership. It is considered as a preliminary step to the autonomous train technology. The trains remote driving would allow to move the train driver from the locomotive to a fixed and ground control station. For this purpose, a robust and reliable wireless communication solution between the train and the control station needs to be set up. This communication should carry instructions from the driver to the train equipment, and transmit the signalisation information and an high quality video streaming of the view in front of the train.

The Wi-Fi access provided to the passengers during the train travels is also based on LTE communications. Indeed, the connection between the train and the internet is carried out by the LTE thanks to an LTE antenna on the train roof. Then, gateways between LTE and Wi-Fi on board the trains allow the internet passengers access via Wi-Fi.

However, the railway environment presents specific Electromagnetic Interference (EMI) sources [2] which can affect the LTE downlink communications. In particular, we study the LTE susceptibility to transient EMI sequences produced by the catenary pantograph contact. Previous studies on other communication systems demonstrated the impact of such interference on the communication quality [3]. Each application based on LTE communications requires a certain throughput, so we have to control if the LTE communications is still able to handle the user demands while being affected by on board EMI. In order to access the LTE behavior in such unfavorable situations, a test methodology is necessary.

Electromagnetic (EM) susceptibility test standards are normally conceived for evaluation of electronic devices. In other words, these standards do not cover wireless communication systems such as LTE. Furthermore, the EMI waveforms in standards such as the EN 61000-4-4 do not necessarily represent the transient railway EM interference produced by catenary-pantograph contact losses. For example, while the mentioned test standard suggests a test signal composed of a series of transients with a fixed repetition rate, on board measurements showed that the time interval between the successive transient can significantly vary [4].

In this paper, Section 2 is dedicated to an overview of the LTE communication protocol and the description of the transient interference model employed for the tests. Section 3 presents the susceptibility test methodology proposed, in describing the quality indicator used and the test bench. Finally, in Section 4, we presents and analyse the results.

2 The LTE protocol and the considered EMI

2.1 Overview of LTE

LTE involves at least one base station (eNodeB) and one mobile station (user equipment: UE). The UE to eNodeB signal transmission is the Uplink (UL) and the eNodeB to UE signal transmission is the Downlink signal (DL). The LTE can be implemented in Frequency Division Duplex

(FDD) or in Time Division Duplex (TDD). In FDD, different frequency bands are allocated to the Uplink and Downlink signals. In TDD, the same frequency band is used by both links but at different time periods. One of the main features of LTE is Orthogonal Frequency Division Multiple Access (OFDMA). The subcarriers frequencies are spaced by 15 kHz which corresponds to 66.7 µs symbol duration. One LTE subframe includes 14 symbols for a 1 ms total duration. Ten subframes compose a frame. A Resource block (RB) is composed of twelves subcarriers, being 180 kHz. Several parameters can vary in a LTE communication. In particular, different modulations from Quadrature Phase-Shift Keying (QPSK) to 64 QAM can be used and channel bandwidths can be 1.4, 3, 5, 10, 15 or 20 MHz. In our work, we study how the reception of the Downlink LTE communication signal can be affected according to the transient EMIs characteristics.

2.2 The railway EM disturbances

The EMI considered is the EM transient generated by the losses of contact in the train powering system. Indeed, the pantograph which slides along the catenary, frequently loses contact, inducing EM discharges. The resulting radiated transient EMIs were measured and characterized during on board measurement campaigns in order to analyse their impact on the GSM-R communication system [4]. To perform test in laboratory, the waveform model extracted from this previous study is employed. Indeed, LTE susceptibility analysis is performed in band 8 (LTE 900) which is adjacent to the GSM-R band. We then assume that the EMI model performed for GSM-R band and expressed by eq. (1) is relevant for this LTE band.

$$Vtrans(t) = A \cdot \left(e^{\frac{-t}{t_{rise}}} - e^{\frac{-t}{t_{hold}}}, \right) \cdot \sin(2\pi f_C t) \cdot u(t) \quad (1)$$

where A is the signal amplitude, $u(t)$ is the unit step function, t_{rise} and t_{hold} are the rising and holding times and f_C is the center frequency of the communication channel. The values of rising and holding times were defined in order to fit with the range observed during the on-board measurements, *i.e.* t_{rise} = *0.4 ns and* t_{hold} = *10 ns*, and also in order to obtain a relatively flat EMI spectrum over an entire downlink LTE channel, as we can see on Figures 1 and 2.

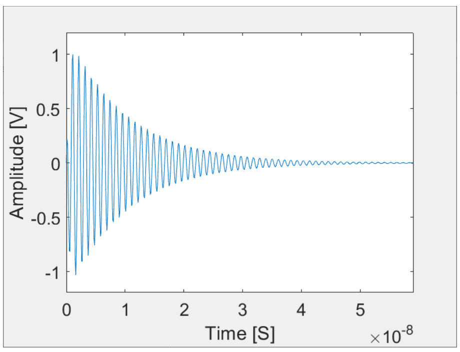

Figure 1. Transient EMI generated with MATLAB

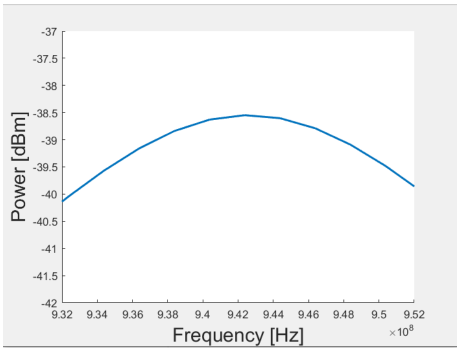

Figure 2. Transient Frequency response

Those parameters define a single transient but in practice, transients occur frequently with short intervals of some µs between successive transients, and due to this repetition, they can impact the LTE communications. Generally, in laboratory tests, transient EMIs sequences are defined with constant time intervals between transient to ensure the test repeatability. However, on board train, transient EMI occurs with variable time intervals. We have then tested two types of sequences with constant (Fig. 3) and variable (Fig. 4) time intervals, in order to assess the relevance of a test method with a constant time interval. To be able to compare the results with constant and variable intervals, the transient sequences with variable intervals were created to respect an average time interval.

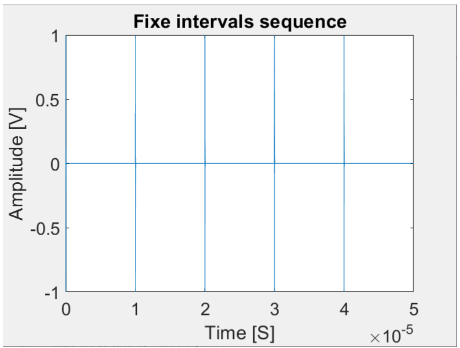

Figure 3. Sequence with a 10 µs constant time interval between successive transients

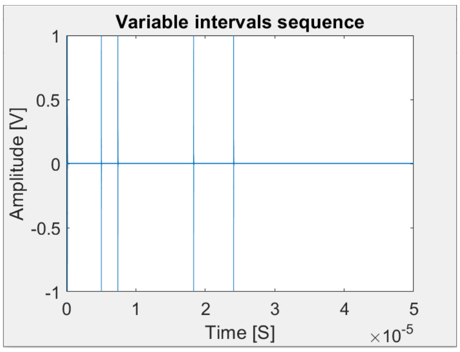

Figure 4. Sequence of transient variable intervals, mean interval = 10 µs

3 The LTE susceptibility test methodology

3.1 LTE Quality indicator: BLER

In order to evaluate the impact of the EMI transient sequences on the DL signal quality, we used the BLock Error Rate (BLER) which is based on the acknowledgement (ACK) signal. Acknowledgement is a native feature of the LTE protocol to indicate if the message sent by the eNodeB has been received without error by the UE. In more details, if there is no error on the received data, the UE sends to the eNodeB an ACK message. If the data is corrupted, the UE sends a non-ACK (NACK) message.

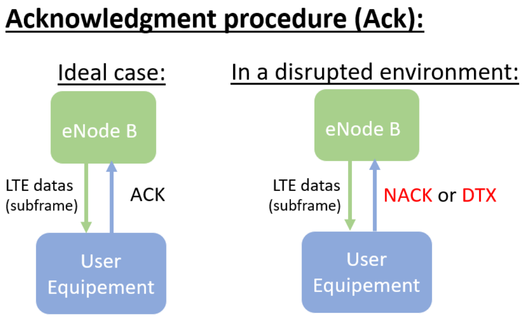

Figure 5. Diagram of the Acknowledgment process

Lastly, if the UE does not send back a NACK or ACK, because the signal has not been detected, the eNodeB considers a DTX status for Discontinous Transmission Detection (Fig. 5). BLER is calculated as with eq. (2).

$$\text{BLER} = \frac{\text{number of }(\text{NACK}+\text{DTX})}{\text{number of }(\text{ACK}+\text{NACK}+\text{DTX})}. \quad (2)$$

3.2 Test bench and test process

The used test bench includes a CMW500 radio communication tester which represents the eNodeB, a AWG 70001a waveform generator generating interference sequences, a LTE dongle (UE) and splitters, as illustrated in Fig. 6.

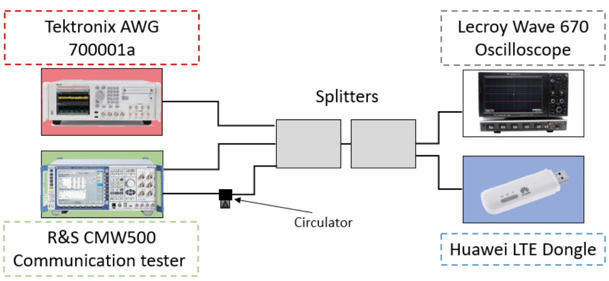

Figure 6. Test bench used to assess the LTE communication susceptibility in the presence of interference.

The measurement process starts with the establishment of the LTE communication between the CMW500 and the LTE Dongle. Then, we launched the AWG to continuously generate the interference sequence for a given mean time between transients once with constant time intervals, once with variable time intervals. We collected ten successives BLER value measured by the CMW500 for each configuration. Finally, we measured the Signal-to-Interference Ratio (SIR) and we compare the BLER values for the two types of sequences, *i.e.* constant vs variable intervals.

3.3 SIR measurement

The SIR calculation and control is necessary to observe the LTE system under different EMI levels. However, this is not an easy task due to certain signal characteristics, *e.g.* those presented in Section 2.2. The transient nature of the interference makes obtaining the SIR questionable. We then described a precise SIR calculation procedure.
In order to know the SIR observed by the UE when a fixed-power LTE DL signal is sent by the eNodeB and a transient EMI sequence is produced by the catenary pantograph contact, we have to split the signals. The acquisition of each waveform is possible thanks to an oscilloscope connected to the testbed in parallel with the UE's input terminal.
In a first step, we turn on the LTE emulator (CMW500) and the UE, while we turn off the signal generator. Then, we adjust the oscilloscope configurations in order to capture a faithful version of the LTE signal in the time domain. To do so, we use a sufficiently high sampling rate (10 GSa/s) and a sufficiently large observation window (we used 100 μs, which is larger than the LTE symbol plus cyclic prefix time, 71.9 μs). Once this signal is acquired, we turn off the CMW500 and activate the signal generator. Now, our criteria to define the observation window is that it must comprise 10 transients. Therefore, the window size becomes a function of the average time interval between transients (see Figs. 3 and 4). We considered time intervals between 0.5 μs and 50 μs so the observation window ranges from 5 μs to 500 μs. In addition, we considered the 100 μs interval, which would require a 1 ms observation window. Generating this signal at 10 GSa/s is, however, unpractical so in this case only 5 transients were recorded in an observation window of 500 μs.

The last step is a post-processing of the signals acquired from the oscilloscope, performed with a simple MATLAB routine. Each signal is processed by a 20 MHz bandwidth filter, centred on the 932-952 MHz LTE DL channel. We then calculate the average power levels of each waveform based on the squared voltage and the 50 Ω impedance. The LTE and EMI power levels obtained, allow us to calculate the different SIRs.

4 Experimental results

Figures 7 and 8 illustrate the BLER measurement results. For these measurements, the LTE communication was configured in QPSK with a 20 MHz bandwidth channel. The results are given for transient sequences with average time intervals of 1 µs, 2 µs, 5 µs, 10 µs, 50 µs and 100 µs. For each scenario, we repeated 10 times the measurement on 35000 subframes, meaning an observation duration of 35 secondes. Each point in the graph represents one BLER measurement expressed in percentage. Finally, we managed to keep the SIR at 14 dB in order to be able to compare those different scenarios.

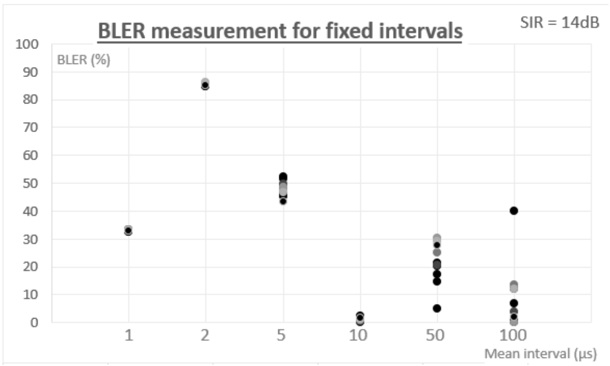

Figure 7. BLER measurements for a LTE Band 8 QPSK 20 MHz communication facing transient sequences with a constant time interval.

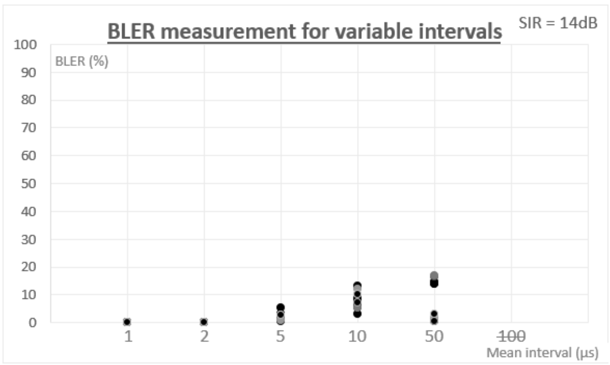

Figure 8. BLER measurements for a LTE Band 8 QPSK 20MHz communication facing sequences of transient with a variable time interval.

In Fig. 7, we observe high BLER values for 1 µs, 2 µs, 5 µs which are above 30 % and lower values for 10 µs, 50 µs, 100 µs (although an outlier can be observed at 100 µs). This suggests that the LTE communication is more sensitive to frequent transient occurring. However, the values measured for 50 µs and 100 µs are spread between 0 % and 30 % and between 0 % and 40 %, respectively. This results spreading shows that a single measurement is not adapted to determine the transient impact on the communication quality.
In Fig. 8, the BLER stays under 20 % for each mean time interval tested. We observe a significant results dispersion (0 to 20 %) for the higher time intervals which is, however, reduced when compared to that seen in Fig. 7. In this case, we were not able to measure the BLER for a 100µs average interval because of the frequent connection breakdowns between the CMW500 and the dongle due to the interference.

The comparison of the two charts shows that applying a constant or variable time intervals impacts significantly the BLER and thus the communication quality. BLER reaches significant higher values when time intervals are constant in relation to variable time intervals. That is probably due to the specific spectrum (frequency comb) over the LTE channel of transient sequences with short and constant time intervals. Moreover, we notice that when the time interval exceeds 10 µs, the BLER results significantly vary, and a statistical measurement process seems to be necessary. Finally, figures 7 and 8 show that a test sequence with constant time intervals can be a significantly more aggressive EM environment than the railway reality.

5 Conclusion

In this paper, we introduced a test methodology to be potentially applied to the planning of LTE networks in railway conditions. It aims to assess the potential weaknesses of the communication system face to transient interferences very common in the railway environment. It can allow us comparing the LTE susceptibility according to the modulation and the channel width. The proposed methodology is based on traditional EM susceptibility test standards but with some adaptations, the main one related to the EMI test waveform. Experimental results indicate that the traditional test waveform with constant characteristics can be inappropriate to control the real susceptibility of modern communication protocol, such as LTE.

References

[1] Masson, Emilie Richard, Philippe Guillen, Santiago Adell, Gemma. (2019). "TC-Rail: Railways Remote Driving".

[2] V. Deniau et al., "Analysis of the Susceptibility of the LoRa Communication Protocol in the Railway Electromagnetic Environment," 2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), 2021, pp. 1-4.

[3] G. Romero, V. Deniau and E. P. Simon, "Impact of the Measurement Methods on the Characterization of Transient Electromagnetic (EM) Interferences above 2 GHz in a Railway Environment," *2019 URSI Asia-Pacific Radio Science Conference (AP-RASC)*, Delhi, March 2019.

[4] N. B. Slimen, V. Deniau, J. Rioult, S. Dudoyer, S. Baranowski, "Statistical characterisation of the EM interference acting on GSM-R antennas fixed above moving trains." *The European Physical Journal Applied Physics*, 2009, 48(2), 21202.

[5] M. Idrees Magray and G. S. Karthikeya and Khalid Muzaffar and Shiban K. Koul, "Compact Co-design of Conformal 4G LTE and mmWave 5G Antennas for Mobile Terminals" *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, 2009, 48, 21202.