Analysis and Modelling of the EM Interferences Produced above a Train associated to the Contact between the Catenary and the Pantograph

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Abstract— **This paper deals with the analysis of the transient disturbances produced above of a train by the pantograph-catenary power supply system. The goal is to study the contribution of the different elements of the train and the infrastructure on the electromagnetic disturbances which are received by communication antennas presents on the roof of the trains. A train simulation model is performed in order to permit us to perform the complete parametric analysis, notably allowing the variation of the antennas characteristics. The disturbance sources considered are those coming from the losses of contact between the pantograph and the catenary wire and the opening and closing of the High Speed Circuit Breaker (HSCB). This paper is validated by experimental results that assess the quality of the designed simulation model.**

Keywords—Transient disturbances; Railway; GSM-R; modeling; time-frequency analysis

I. INTRODUCTION

In the framework of the European project TREND, one of the objectives is to realize a realistic model of a train and the infrastructure surrounding, in order to model the coupling mechanisms existing between the main disturbing railway elements and the GSM-R antennas fixed on the train. Indeed, preliminary works highlighted that the losses of contact between the catenary and the pantograph generated wide band interferences which can disturb the GSM-R signals received by the train [1]. In TREND, we therefore aim to design a model of these phenomena in order to study the impact of the position of the GSM-R antenna on the received interferences.

However, knowing that the frequency band to consider is between 920 MHz and 925 MHz (GSM-R down link signals), a too complex train model would be difficult to handle due to the calculation time. A preliminary task was then to perform measurements in order to identify the main coupling and to limit the model parameters to the main elements acting on the interferences received by an antenna. This measurement campaign provided preliminary experimental results in order to perform comparisons with simulation results. This paper presents the details of a measurement campaign performed in Toledo, in Spain, on a static train, as shown in the following section. The experimental results are analysed in time and frequency domains in order to extract significant observations which can be taken as reference to assess a simulation model. Finally, a simulation model of the train roof, carried out with CST microwave studio simulation tool is presented and assessed by comparison with experimental results.

II. MEASUREMENT CAMPAIGN DESCRIPTION

A. Train configuration and scenario measurements

The measurements were performed on the OARIS high speed train provided by the Spanish rolling stock company CAF. The general description of the train is given on Fig. 1.

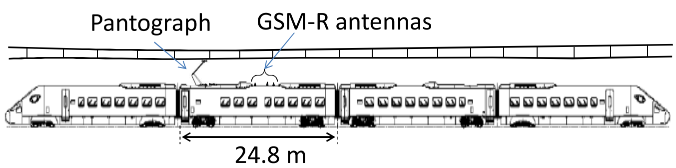

Fig. 1. Representation of the train on which the measurement campaign was performed.

The measurements were performed with the antennas located on the roof of the second car and on a supplementary antenna placed on the track side near by the second car of the train. The train is equipped with 2 pairs of pantographs composed by one for 3kV DC and one for 25kV 50Hz operation. Each pair located in the central cars. Only one of the pantographs can be connected and the second one provides redundancy in case of failure. The measurements were performed on a 25 kV 50 Hz line and the pantograph employed is the second car one as represented on Fig.1.

In order to generate transient EM disturbances coming from the catenary-pantograph contact and to perfectly control the configuration, the measurements were performed without moving the train. So, transient disturbances were artificially provoked by connecting and disconnecting the pantograph to the catenary. To avoid any damage on the equipment of the train, the High Speed Circuit Breaker (HSCB) was opened before disconnecting the pantograph and closed after its connection. So, for each series of measurement, the following actions were carried out:

- Opening the HSCB
- Disconnecting the pantograph
- Connecting the pantograph and
- Closing the HSCB

B. *Measurement equipments*

The measurements were carried out using four antennas connected to the four oscilloscope inputs. Three of the antennas were antennas already present on the train and covering the GSM-R frequency band. The reflection S-parameters of these 3 antennas are given Fig.2, where we notice that one antenna is significantly more efficient in the considered frequency band.

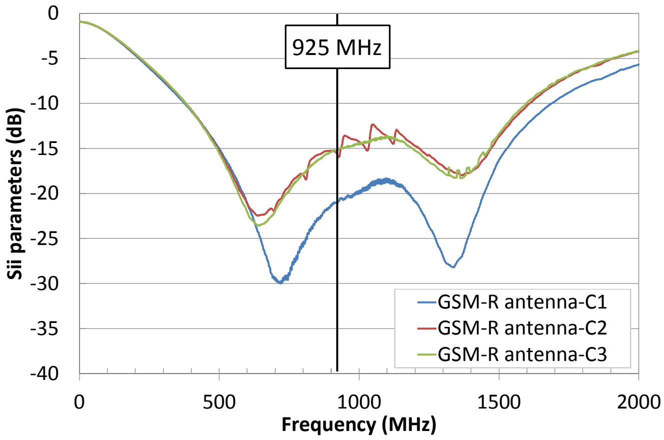

Fig. 2. Sii parameters of the three GSM-R antennas fixed on the train roof.

However, due to the position of the three antennas being fixed; a supplementary home-made antenna was employed and placed on the track side of the train. This antenna was designed in order to be easily modelled in the simulation tool, and to cover a relatively wide frequency band, also including the GSM-R frequency band. Moreover, the antenna had also to perfectly filter the lowest frequencies under some 100 MHz. Indeed, knowing that the measurements were performed with an oscilloscope, it was important to filter the lowest frequency in order to optimize the dynamic resolution of the oscilloscope according to the frequency of interest. The antenna, its radiation pattern and its reflection S-parameter are represented Fig. 3, 4 and 5.

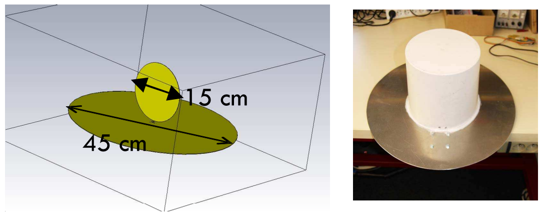

Fig. 3. Representation of the home-made antenna, covered by a radom on the right protograph.

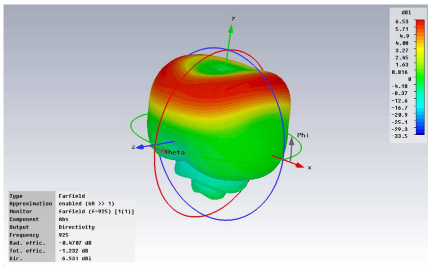

Fig. 4. Radiated pattern of the home-made antenna at 925 MHz.

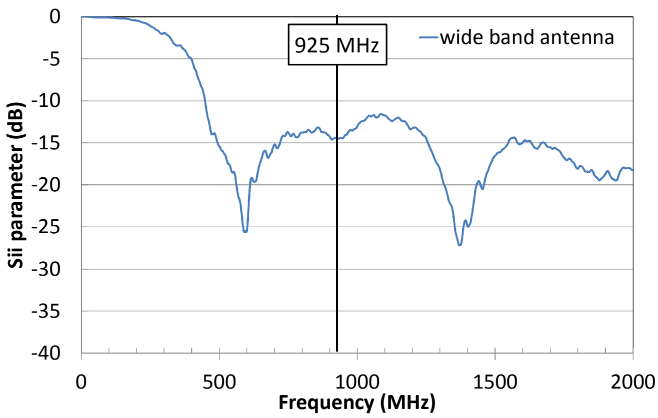

Fig. 5. S11 parameter of the home-made antenna placed on the track side of the train.

This home-made antenna is almost a metallic vertical circle and from now, it will be called “circle-antenna”. The transient signals were measured with an oscilloscope, applying a frequency sampling of 10 GS/s. The triggering level was defined on the Channel 1 connected to one of the GSM-R antennas. Each time that the triggering level was reached on this Channel 1, four simultaneous windows measurements corresponding to the four antennas were collected.

C. *Measurement configuration*

To specify the measurement configuration, Fig.6 presents the top view of the train second car, along which the circle-antenna was moved.

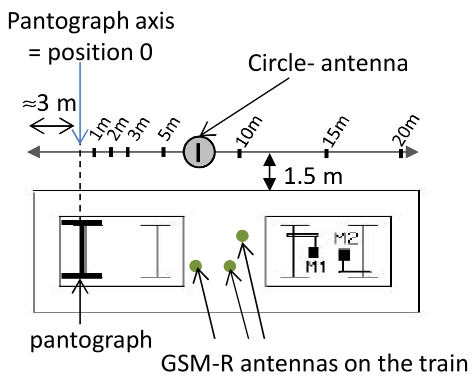

Fig. 6. Measurement configuration along the second car of the train.

As illustrated Fig. 6, the position of the circle antenna was modified. Taking the axe of the pantograph as reference, the antenna was moved from 3 m before the pantograph to 20 m after the pantograph. The height of the antenna was approximately at 3 m from the floor and 0.9 m from the train roof. A photograph of the circle-antenna on the track side is given Fig. 7.

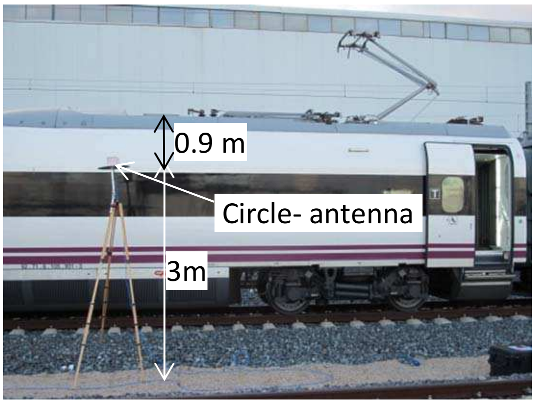

Fig. 7. Photograph of the circle-antenna on the side of the train.

III. Measurement Results

A. *Comparison between the transients received by the four antennas*

For each position of the circle antenna, the driver of the train acted on the HSCB and the pantograph according to the process mentioned in the previous section. For each action of this procedure, when a transient was detected on the triggered channel 1 of the oscilloscope, the four time windows corresponding to the four antennas were collected simultaneously. For example, Fig. 8 presents the four transients received by the antennas when the HSCB was closed. For this measurement, the circle antenna (Channel 4 on Fig. 8) was 1 m away from the axe of the pantograph.

Fig. 8 shows the differences between the transient signals received by the four antennas while the source is identical. Behind, the three GSM-R antenna, the first one connected to the channel 1received a more important transient. That can be explained by the fact that its reflection S-parameter is lower than the Sii-parameter of the two other GSM-R antennas. Nevertheless, we also notice that the transient collected on the channels 1 and 2 are also different whereas the levels of their reflection parameters are hardly different. Concerning the circle antenna, we observe that the transient received is significantly higher than those received by the other antennas, due to its wider frequency band design. These results highlight the impact of the antenna characteristics on the received disturbances and demonstrate that an efficient simulation model of the train requires a perfect modelling of the antenna.

In the following sections of the paper, the priority will be given to the results obtained with the GSM-R antenna of the Channel 1 and the circle-antenna connected to Channel 4.

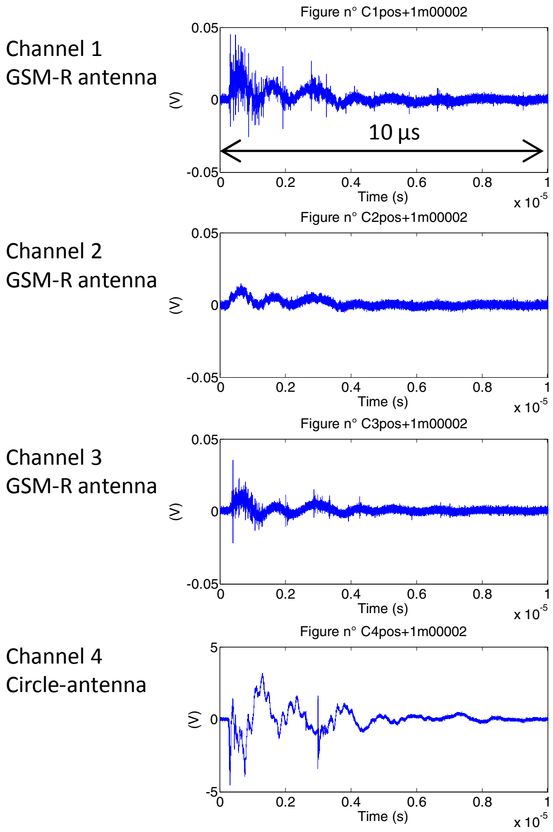

Fig. 8. Illustration of the transients received by the four antennas when the HSCB is closed.

B. *Comparison between the transients produced by the four actions*

The transients received on the channel 1 connected to a GSM-R antenna are presented Fig.9. These transients are observed over a 1 ms time windows. These results shows that the difference between the transients produced by the four actions. In particular, the lowering of the pantograph is the only one action that produces a succession of transients over the 1 ms time windows. Moreover, the opening of the CB and the lowering of the pantograph produced very short time transients while the rising of the pantograph and the closing of the CB induced transient events significantly longer, of several µs.

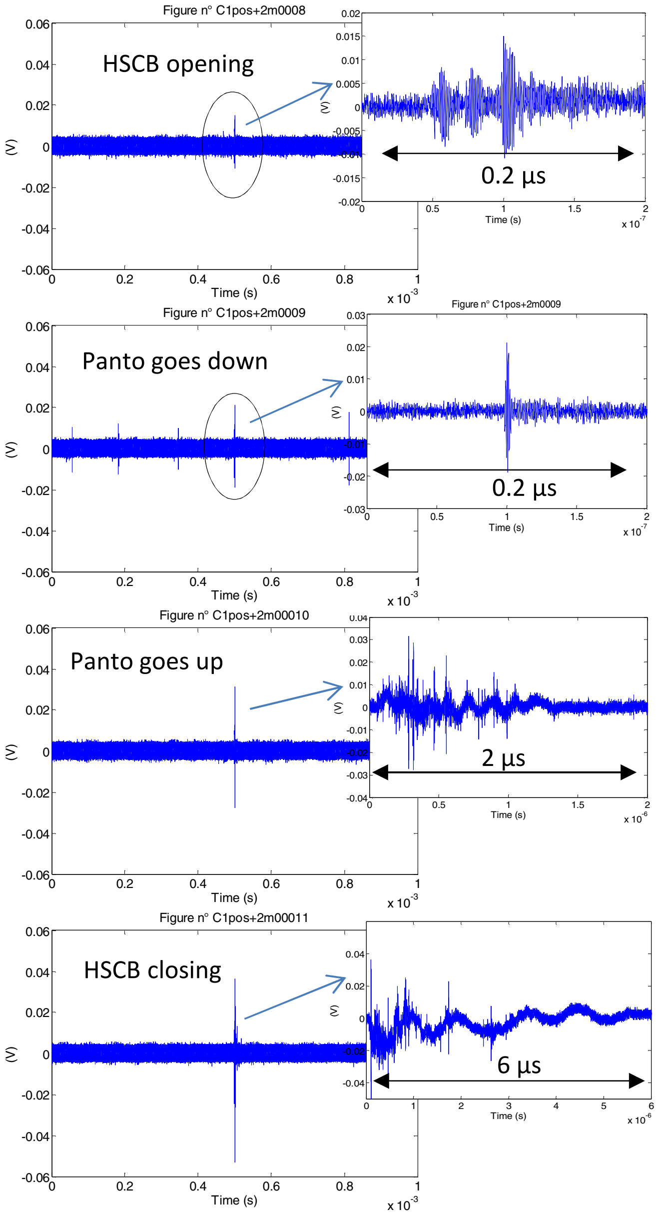

Fig. 9. Illustration of the transients received by a GM-R antenna when the HSCB is opened and closed or the pantograph goes down and up.

These observations can come from the voltages of the pantograph and the catenary. Indeed, the opening of the CB and the lowering of the pantograph correspond to the disconnection of two elements at the same potential, whereas the closing of the CB and rising of the pantograph correspond to the connection between two different voltages elements. However, these last transients can also be considered as a succession of several short time transients.

IV. Impact of the Reception Antenna Position

In this section, the study is focused on the transients induced by the lowering of the pantograph. The briefness of these transients facilitates the analysis of the impact of the measurement antenna position. Moreover, the time characteristics of the transient produced by the lowering of the pantograph are more similar to the characteristics of the transients observed on-board moving train [2]. All the results presented in this section are obtained with the circle-antenna which is the only one moved along the train and which can be precisely modelled.

A. *Time frequency analysis*

The analysis of the measured transient in the time domain cannot be rigorous due the presence of permanent noises superimposed to the transient signals. Moreover, we want to assess the impact of the position of the measurement antenna on the time characteristics of the transient and on the frequency distribution. We then performed a time-frequency analysis applying a sliding Fast Fourier Transform on the time domain measurements [3]. The FFT calculation was performed with 128 points hamming windows corresponding to 12.8 ns, which expression is given by (1).

$$w(t) = 0.54 + 0.46\cos\left(2\pi \frac{t}{T}\right) \quad \text{for } t \in \left[-\frac{T}{2}, \frac{T}{2}\right] \qquad (1)$$

An overlapping of 75 % is applied between the successive windows. The calculation principle is illustrated by Fig. 10. The upper graph represents the transient measured by the circle antenna placed at 1 m from the pantograph axe. On this graph, we represented the 128 points window applied to calculate the sliding FFT. The second graph represents the results of the sliding FFT on the transient measured at 1 m from the pantograph.

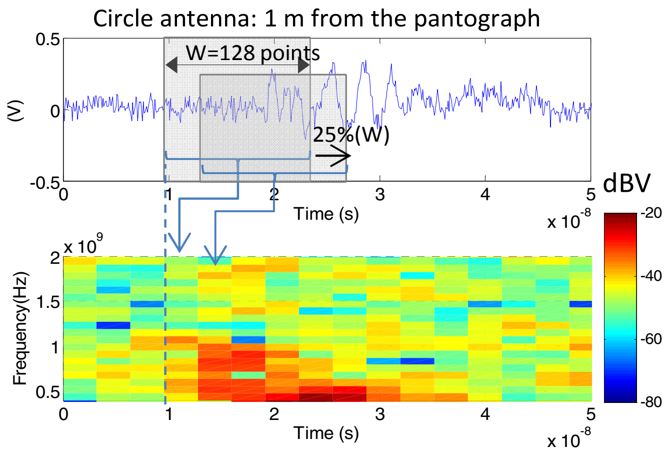

Fig. 10. Illustration of the sliding FFT calculation applied on the time domain results.

In Fig. 11, the results of the FFT calculation applied to the measurement for different positions of the circle antenna are presented over a 200 ns time duration. The results are presented between 400 MHz and 2 GHz. On the representation, the GSM-R frequency band is represented by a vertical dotted line.

Due to the triggering level being defined on the Channel 1 connected to the GSM-R antenna at a fixed position on the train, the results permit us to observe the evolution of the Δt

delay propagation according to the position of the receiving home-made antenna. Indeed, all the time windows collected for the different positions of the antenna are finally synchronized taking as reference the reception time of the transient event by the GSM-R antenna.

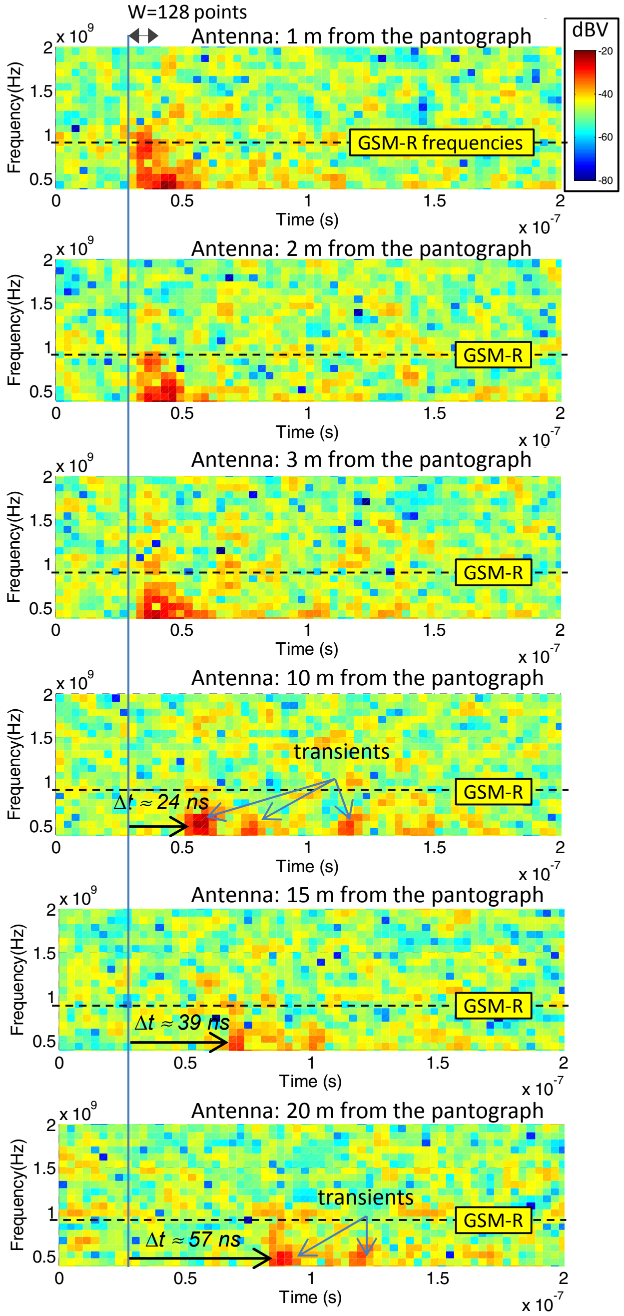

Fig. 11. Time-frequency analysis of the transients received by the circle antenna at different positions, when the pantograph is disconnected from the catenary wire.

In the results at 1 m and 2 m from the pantograph, only one transient event is observed. However, at the other 10 m, 15 m and 20 m positions, several transient events are visible. That illustrates the presence of reflection signals inside the structure, which also act on the interferences received by the antenna. Moreover, the time delays are inferior to the time delays expected from a punctual source which could localized at the interface of the catenary and the pantograph.

V. SIMULATION MODEL

A. Description of the model

The model was carried out with CST microwave studio simulation tool [4], based on the finite-integration technique, which is more adapted to the analysis of transient phenomena [5-6]. It aims to simulate the effect of radiated emissions from pantograph arcing on the GSM-R.

This model illustrated in Fig. 12 consists of:

- Radiation source between the pantograph and the catenary
- Pantograph (formed by perfect metallic conductors)
- catenary metallic wire
- Antennas matched at the GSM-R frequency.

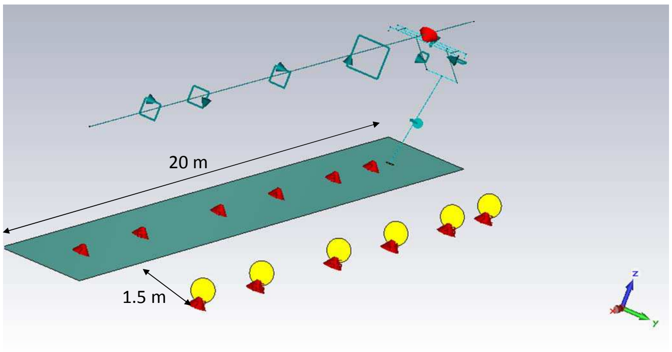

Fig. 12. Illustration of the CST model.

The model was also designed considering the calculation time duration. In order to reduce model complexity and save time simulation, we use some simplifications:

- The metallic conductors of both catenary and pantograph are modelled as a wire conductor without meshing inside. On the other hand, there is no need to model all the train, a roof of the train modelled by a metallic surface plan is sufficient for our study. Furthermore, to simulate an infinite effect of the catenary, the roof of the train and avoid reflections we chose to set the conditions limited as open boundaries.

These approximations allow us to keep simulation time about three hours with satisfying accuracy.

B. Source and antenna characteristics

The radiation source is modelled by a vertical discrete port placed at the interface between the catenary and the pantograph. This port excited by a transient signal simulates the radiated emission of an electric arc. The transient signal source applied is a Gaussian transient which time characteristics were defined in order to cover the frequencies up to 1 GHz. Fig. 13 represents the time excitation transient signal and its frequency spectrum. At this step, the maximal value of the sources signal was arbitrarily defined; the precise definition of the source signal not being the goal of this paper.

To compare the experimental and the simulation results several identical antennas, modelling the circle-antenna, were introduced in the model to investigate the effect of the distance from the pantograph. The antennas are placed at 1.5m from the metallic plan which models the roof of the train. The transient received by the antennas at different distance will be compared.

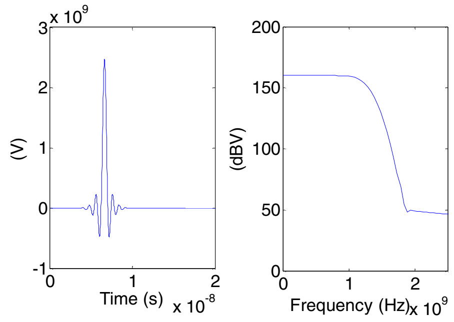

Fig. 13. Characteristics of the signal excitation in time and frequency domains.

This step aims to assess the model by performing comparison with experimental results and to analyse the impact of distance on the received disturbances. Obviously, in the future steps, the antenna will be placed on the metallic plan in order to better model the real configuration of the GSM-R antennas.

VI. SIMULATION RESULTS

Unlike experimental signals, time domain analysis is much easier on the signals obtained by simulation. Indeed, the results are not affected by the presence of environmental EM noise. Thus, the delays associated with the position of the antenna are perfectly observable in Fig. 14. These results show that the time delays induced by the position of the receiving antenna are comparable to those obtained experimentally (Fig.11).

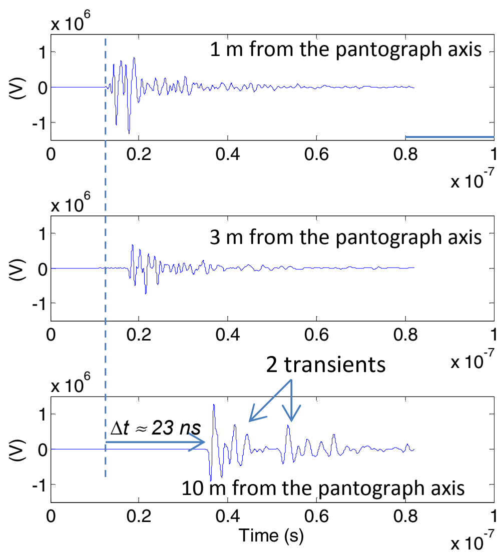

Fig. 14. Simulation transient signals received by the circle-antenna at different distances.

Moreover, when the antenna is at 10 m from the pantograph axe, we also notice the appearing of a secondary transient, like in the measurement results, which can come from the reflection of the original transient signal inside the structure.

VII. CONCLUSION

This paper presents the approach which is developed in the TREND project in order to identify the main parameters which act on the disturbances received by GSM-R antennas placed on the roof of the trains. Experimental results highlight the variation of the transient signal characteristics according to the actions on the HSCB or on the pantograph. Moreover, these results showed also the significant impact of the antenna on the received transients and then the importance to correctly model it. Measurements performed at different distances from the pantograph permitted us to observe significant differences on the transient signals received according to the distance. Differences were notably noticed concerning the frequency band covered by the transient and at certain distances reflection phenomena create the appearing of supplementary transients.

A relatively simplified simulation model was carried out in order to try to reproduce the phenomena observed in measurements. The first simulation results showed the appearing of reflected transients which is in agreement with the experimental results. However, at this step the simulated transient source was arbitrarily defined and to perform more significant comparisons, it is now necessary to adequately define the transient signal source.

ACKNOWLEDGMENT

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