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# An Audio Frequency Model of a 2x25 kV Traction Line for High Speed Railway Systems

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*Abstract*: - The new Italian high-speed railway lines are characterised by a 2x25 kV – 50 Hz electrification standard. Train operation is carried out by the innovative ERTMS level II signalling system that is supported by audio frequency track circuits (AF-TC). The choice of the audio frequency is due to the necessity of eliminating the interference problems between 50 Hz traction currents and track circuit operation.
The paper illustrates the audio frequency models, implemented in Alternative Transient Program (ATP), of both the electrification system and the track circuits. Interferences between traction harmonic currents and track circuit operation, compromising the system availability degree and the transportation regularity, are here analysed. The main results, concerning system resonance frequencies and rail current distribution, are presented and discussed.

*Key-Words*: High Speed Railway Lines, Track Circuits, Audio Frequency, Harmonic Currents, Resonance Frequency

## 1 Introduction

The new Italian high-speed railway lines are characterised by a typical 2x25 kV – 50Hz electrification system [1]. In this context train operation is carried out by the innovative ERTMS level II signalling system that is supported by audio frequency track circuits (AF-TC). This choice avoids any possible interference between 50 Hz traction currents and track circuit operation. In spite of that, interferences are possible because of the harmonic currents that are injected in the line by the motor drive equipment. This element is not anyway sufficient to determine an improper operation of the track circuit that is exclusively possible in the case that rail currents in the track circuit operational bands are unbalanced and amplified.
In this case track circuits can be affected by unexpected occupations that may compromise the system availability degree and the transportation regularity. In the light of that, an analysis of both the resonance frequencies and the rail current distribution turns out quite useful and important.
Alternative Transient Program (ATP) models have been then implemented with the aim to analyse the audio frequency behaviour of the electrification system [2]. In the paper section 2 reports the system description; section 3 includes the explanation of the audio frequency model; section 4 summarizes the simulation results. Finally section 5 shows the conclusions.

## 2 System Description

As far as line electrification is concerned, the Italian high speed railway network adopts a typical 2x25 kV – 50 Hz configuration, as shown in figure 1, that includes HV/55 kV double secondary transformers, 55/27,5 kV autotransformers, contact wire (CW), messenger (M), feeders (FD), rail return wires (RW) and ground wires (GW).

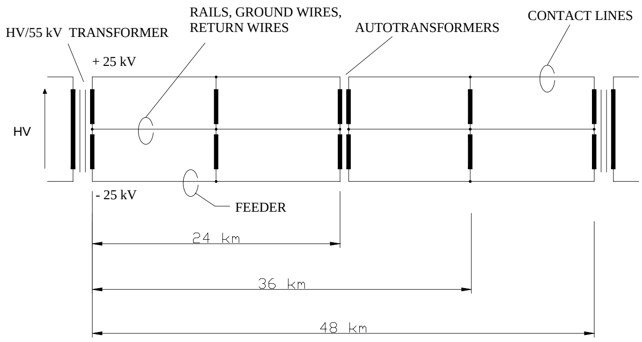


Fig. 1 - Electrical Scheme of a 2x25 kV – 50Hz System

The characteristic geometrical disposition of an embankment/cutting line section is illustrated in figure 2; similar configurations are valid for viaduct line sections and tunnel sections where differences regard basically the position of feeders, returns wires (RW) and ground wires (GW).

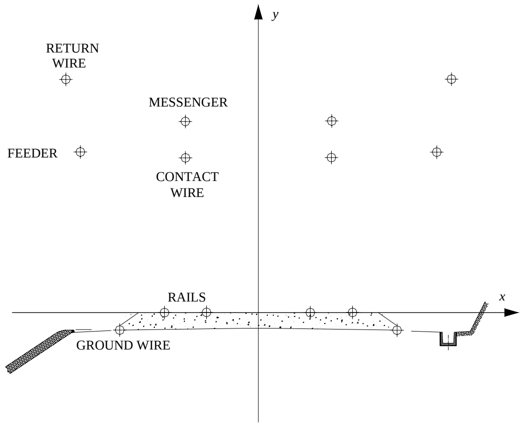


Fig.2 - Embankment/Cutting Line Section

As far as train operation a Level II ERTMS signalling system is implemented including both on-board and trackside equipment [3]-[4]. The train detection sub-system is based in particular on the use of audio frequency track circuits (AF-TC) of which the layout is shown in figure 3.

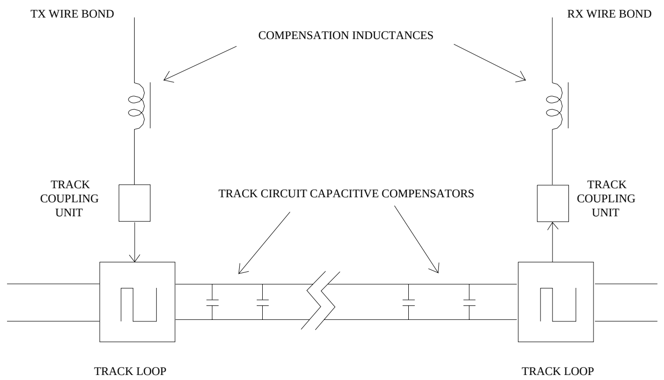


Fig. 3 - Track Circuit Layout

Main trackside components of the AF-TC are track coupling units, capacitive compensators, and S joints (track loops). Track coupling units interface track signals with receiver and transmitter circuits, and provide for tuning to the track circuit carrier frequency. S joints carry out the signal separation between adjacent track circuits.

## 3 Audio Frequency Electrical Model

Alternative Transient Program (ATP), implementing the Carson Pollaczek theory, has been used in order to simulate the audio frequency behaviour of the real system.

Two models have been studied. The former (Model 1), representing both the electrification system and the track circuits [5], is based on 10-meter multipoles while the latter (Model 2), representing the sole electrification system, is composed of 250-meter multipoles. Each multipole is modelled as a black box including self and mutual impedances and self and mutual capacitances.

A synthetic representation of the equivalent $\pi$ circuit for an L-meter line section is illustrated in figure 4:

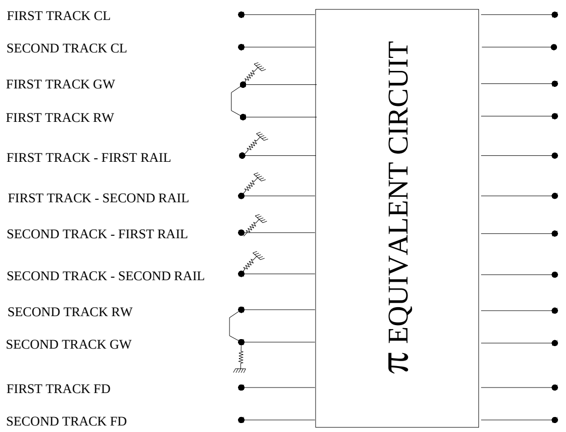


Fig.4 - Synthetic Representation of an L-meter Line Section

A lumped parameter model, assuming the overall resistance is concentrated every L meters of line, represents rail-to-ground leakage. A value of 0.025 S/km has been in particular chosen for rail leakage conductance. As far as ballast, its conductivity does obviously vary with both the maintenance activities and the weather conditions.

The ATP rail model (referred to a UNI 60 track section) has been moreover artificially modified in order to take into account the results of laboratory tests and to give consequently a more realistic representation of the inner resistance and inductance [6]-[7]. A similar model has been assumed for the ground wire.

As far as track circuit model is concerned, coupling units and track loops are represented by Thevenin equivalent circuit in transmission and by specific impedance in reception.

The capacitive compensators are placed every 100 m while the impedance bonds (see figure 5) are placed every 1500 m.

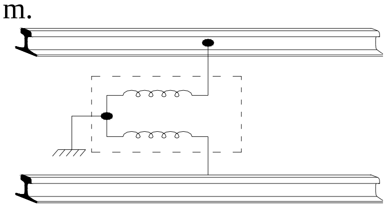

Fig. 5 - Impedance Bond Layout

In order to complete the traction line model, an equivalent circuit of the HV/55 kV - 50 Hz power transformer has been represented in ATP as in figure 6. A similar model is implemented for the 55/27,5 kV autotransformers.

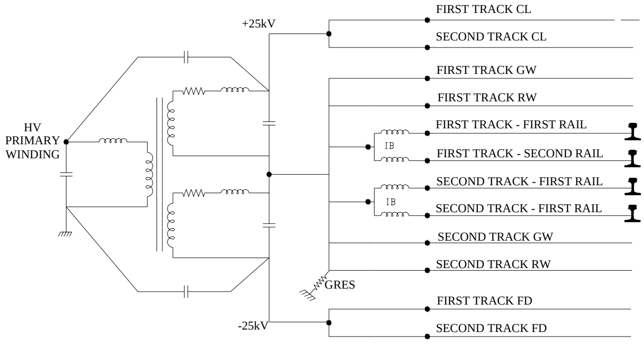


Fig. 6 – HV/55 kV Transformer ATP Representation

Finally figure 7 reports the AF train model: the audio frequency train operation has been represented by a harmonic current generator (10 A) with frequencies from 1.9 kHz to 17.0 kHz. An ideal 1:1 transformer has been introduced between the current generator and the contact line in order to overcome an ATP implementation limit. The model has been applied to each specific operational frequency in the range 1.9 kHz ÷17 kHz.

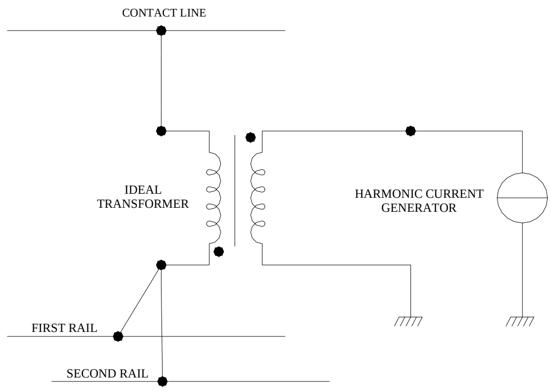


Fig.7 ATP audiofrequency representation of the single train

# 4 Results

## 4.1 Comparison between the models

The results of the application of the two above-described models are illustrated in figures 8 and 9.

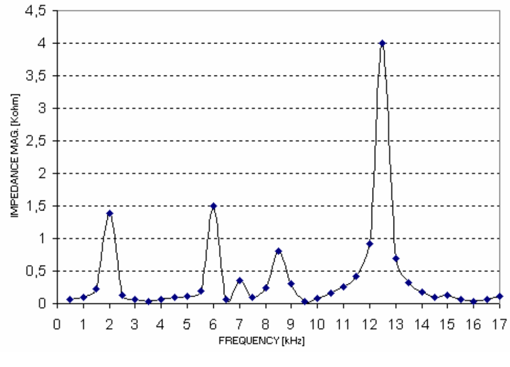


Fig.8 – Magnitude and Phase of Thevenin Impedance - Frequency in Model 1 for Train at km 16

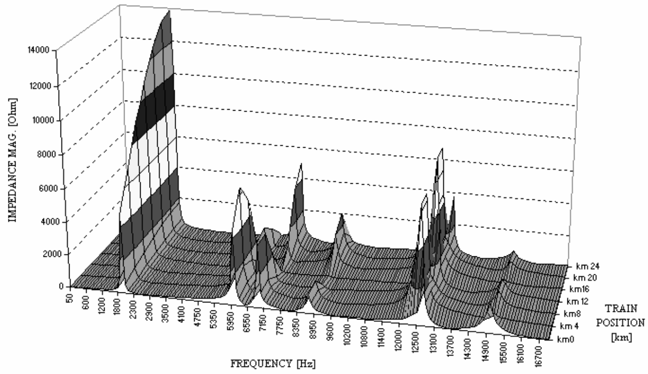


Fig.9 - Thevenin Impedance – Frequency – Train Position in Model 2

A comparison between these results shows a substantial match of both the resonance frequencies and the relevant impedances. The differences in the values of figures 8 and 9 are essentially due to a different frequency sampling (500 Hz for Model 1 and 100 Hz for Model 2). It is then possible and convenient to adopt the simplified Model 2, not including the representation of the track circuits, in order to detect and analyse the resonance frequencies and the current distribution.

## 4.2 Resonance Frequency Analysis

Figures 10 and 11 illustrate the impedance values as a function of the frequency and the kilometric point, for two specific line sections:

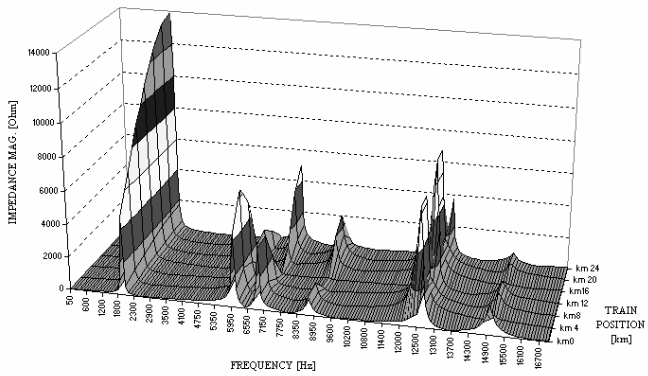


Fig.10 – Impedance – Frequency - Train Position for Embankment/Cutting Line Section

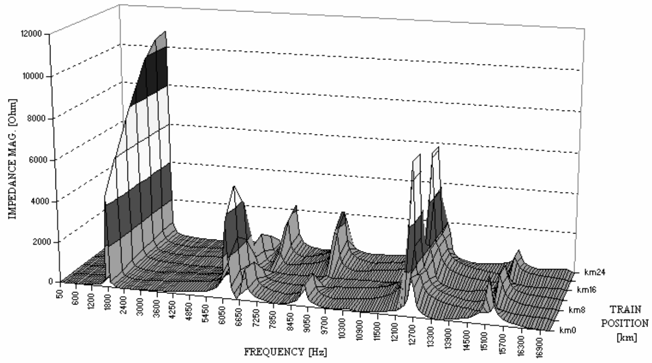

Fig.11 – Impedance – Frequency - Train Position
for natural tunnel line section

These figures show the existence of different resonance frequencies. In particular it is possible to discern a substantial decrease in the resonance impedance peak values as the frequency increases. It can be justified by the increase in the line conductor resistance caused by the skin effect.

It is moreover worthwhile noting that the first parallel resonance frequency of the natural tunnel line section (around 1700 Hz) is out of the first frequency band (190042300 Hz).

The analysis of the frequency spectra of the different line section typologies shows similar profiles and substantially equivalent impedance values. Some differences can however be detected around the parallel resonance frequencies.

Figure 12 illustrates the superimposition between the track circuit operational frequencies and the simulation results obtained for a typical embankment/cutting line section with train at km 20.

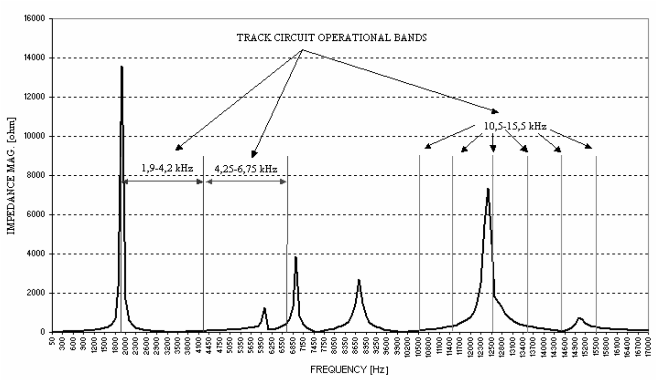


Fig.12 – Comparison between Frequencies

The first parallel resonance frequency for this configuration (train at km 20) is within the range 1800÷2000 Hz that overlaps with the first track circuit band (190042300 Hz). Moreover the first harmonic band of the motor units is around 2000 Hz. For all these reasons this situation can be quite critical.

As the frequency increases above the first parallel resonance, the impedance shows a capacitive behaviour till the amplitude reaches a minimum value corresponding to a series resonance that is a resonance between longitudinal and transversal line parameters.

The last detected parallel resonance frequency is around 15300 Hz that is within the frequency band 15300÷15700 Hz of the track circuits.

Impedance magnitude and phase at 1950 Hz are shown in figure 13 as a function of train position.

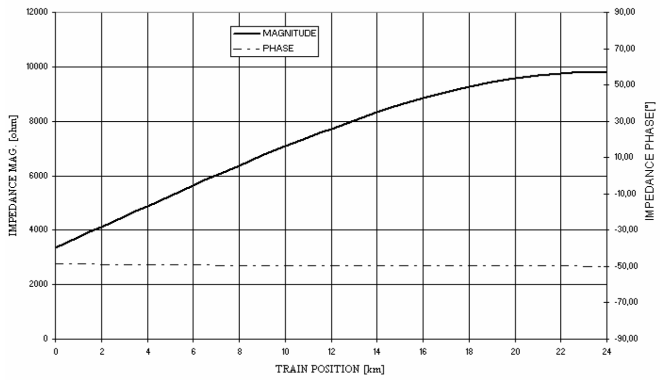


Fig.13 – Impedance Magnitude and Phase
at 1950 Hz - Train Position

The magnitude increases with the train distance from the substation while impedance phase doesn't vary. It means that the first resonance frequency does not depend on the train position. This result matches with the evidences of studies on similar railway lines [8]-[9].

Figure 14 shows the impedance magnitude and phase at 12500 Hz.

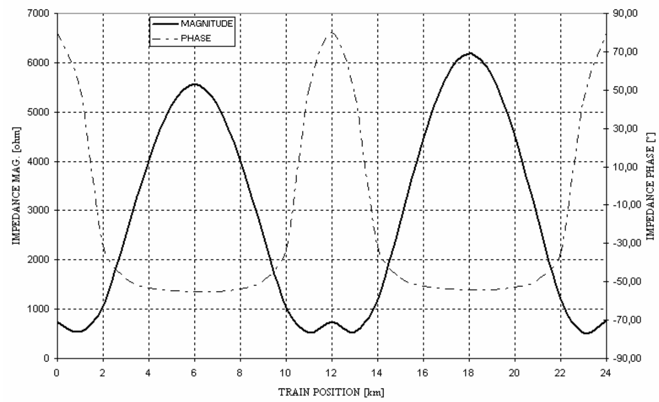


Fig.14 - Impedance Magnitude and Phase
at 12500 Hz - Train Position

Their profiles are symmetrical with respect to the electric section centre, at km 12. The inversion of the phase sign as train position varies, means that the resonance frequency oscillates around 12500 Hz. The particular profile of the impedance magnitude can be explained by the consideration that, for this specific frequency, each half section corresponds to half a wavelength.

This behaviour is even shown by simulations that do not include transformers and autotransformers. Figure 15 shows the disappearance of the resonance frequencies other than 12500 Hz, meaning their dependence from the discontinuities introduced by the electrical transformer.

The resonance behaviour around 6250 Hz is justified by the λ/2 operation of the overall line section.

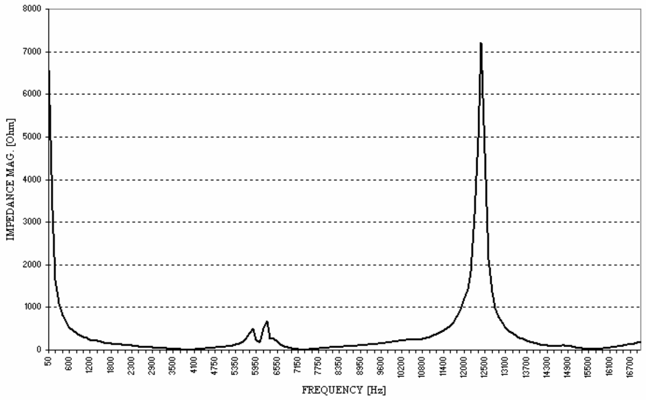


Fig. 15 - Impedance Magnitude - Frequency with Transformers and Autotransformers Disconnected

The last detected parallel resonance frequency is around 15300 Hz. At this frequency the phase curve, reported in figure 16, shows that the resonance frequency is mildly dependent on the train position. It is however worthwhile noting that traction harmonic current amplitude is not high in this frequency range.

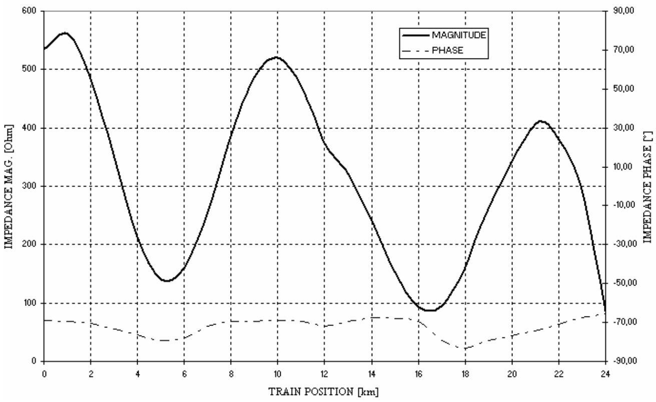


Fig.16 - Impedance Magnitude and Phase at 15300 Hz - Train Position

## 4.3 Current Distribution Analysis

Current unbalance in the rails can cause problems with track circuit operation and it is then considered a disturbance estimation parameter.

The analysis of an embankment/cutting line section is hereby illustrated; the results can be anyway extended to the other line sections. The simulations have shown a significant unbalance around the parallel resonance frequencies.

The first studied frequency is 1950 Hz. A 10A current generator, simulating the train, has been placed at km 20 on the first track. For this case figure 17 shows the rail currents in the first track. Similar values have been calculated for the second track.

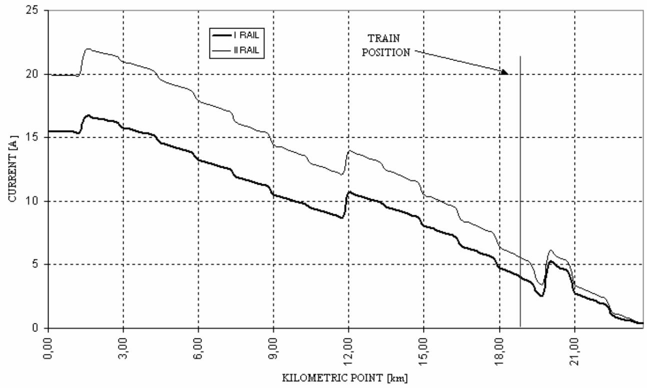


Fig.17 – Rail Currents in the First Track at 1950 Hz

The current unbalance increases as the distance from the substation decreases. This phenomenon can be considered an effect of both the current induction and the line geometrical dissymmetry.

Some discontinuities can be detected every 1500 meters that is where the impedance bonds are connected. A more consistent gap near the centre of the electric line section is caused by the autotransformer operation.

A comparison can be made with the results obtained for a non-resonant frequency, at 4150 Hz for example. In this case figures 18 and 19 show an irrelevant current unbalance (about 1%) and a significant attenuation of the current magnitude.

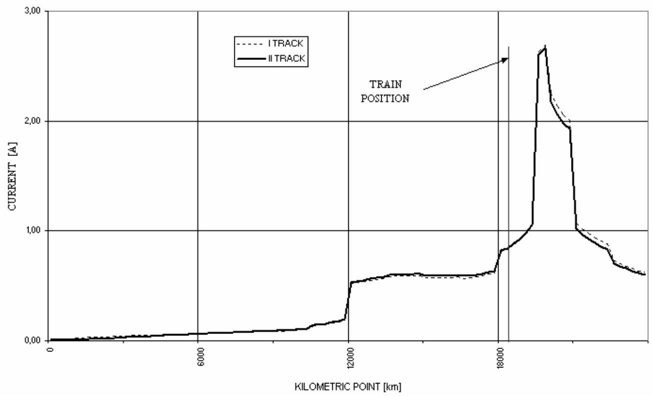


Fig. 18 - Rail Currents in the First Track – 4150 Hz

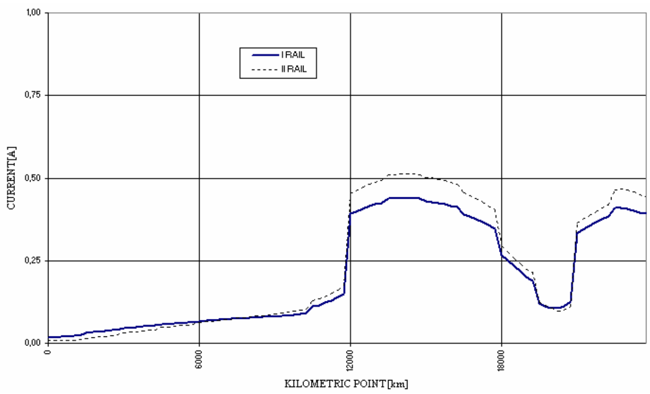


Fig. 19 – Rail Currents in the Second Track - 4150 Hz

## 5 Conclusions

The present study has concerned the detection of an audio frequency model of the electrification system of a 2x25 kV high-speed railway line. The objective was to analyse the interference problems between the traction loads and the audiofrequency track circuits supporting the innovative ERTMS level II signalling system.
The model allows estimating system resonance frequencies that can be compared with motor unit harmonic spectra and track circuit operational frequency bands. Rail current distribution has been moreover studied by model implementation in order to detect possible problems in the track circuit operation.
Results have shown a substantial independence of system resonance frequencies from both the line section typology and the train position. Simulations have moreover shown an evident rail current unbalance around the system resonance frequencies.
Next steps will regard the validation of the audio frequency model by a test campaign.

*Acknowledgements*
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