ELECTRICAL NETWORK MODELING OF LARGE ANTENNA SYSTEMS SUBMITTED TO TRANSIENT PARASITIC EM PULSE

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ABSTRACT

This paper presents the results of the SIMPLEXE project (SIMulation of comPLEXE system) supported by the AID organism of the DGA. In this project, the objective is to capitalize the works made the last twenty years using the Kron's electrical network formalism to analyze large EMC systems such as launch aerospace systems. The highly oversized system studied in this paper is composed of large antennas, buried lines, cable harness, a building, shielding equipment, sensitive electronic devices. Two kinds of EM perturbation have been studied: the direct and indirect lightning discharges. The main objective of the study is to optimize the design of the electromagnetic protection based on parametric EM simulations.

1. INTRODUCTION

In order to model electronic systems including antennas, cables and electronic components, the full waves methods such as FDTD, Method of Moment and finite elements are classically used. But as the systems become more and more complex, they require a large amount of computational resources. Moreover, the multiscale aspect is difficult to be taken into account. To overcome this difficulty, we propose an original approach based on a circuit modelling [1]-[2]. The principle is based on a physical understanding of the coupling phenomena between the different elements of a system. These coupling are then traduced into equivalent electrical circuit that can easily be solves thanks to the proposed Kron approach. One of the interests in to open up new perspectives for a fast parametric analysis and a good comprehension of the systems behaviour. It will ensure the identification of main radiated and conducted coupling paths and the sensitive EM parameters in order to optimize the protections and to control the disturbance sources in antenna system design phases.
This approach will be presented with an example that has been experimentally reproduced. First the structure and the way to solve the problem will be shortly described. After that, some theoretical and experimental results on the system will be given validating the theory.

2. SHORT DESCRIPTION OF LARGE SYSTEMS

The proposed approach consists in firstly making the decomposition of a large system into sub-elements easier to physically analyse separately. Secondly a precalculated model of each sub element is chosen in the library. The choice is made in term of best compromise between physical phenomena representation, precision, and computational resources. Finally, the Kron's electrical network formalism is used to build and to solve the system with schematic and algebraic representation of the physical phenomena. Fig.1 shows a global view of the system under study in this paper: a telecommunication chain and the measurement of the receiving signal performed by Ariane Group.
The measurements are performed in an Anechoic Chamber (AC), the system test case consists in a monopole antenna in reception mode, feeding a buried line which is connected to coaxial cable RG214. In order to make measurements outside the AC, a second coaxial cable transport the signal to an oscilloscope input loaded or not with a diode connected in parallel. The monopole receives a signal emitted by a biconical antenna locate in the AC and supplied from outside the AC by a voltage source delivering a sine wave at 270 MHz, 0 dBm, the magnitude modulation rate is 80% at 100 kHz. Two kinds of EM aggressions are performed:
• Direct Lightning is induced in conduction mode using a Bulk Current Injection (BCI) bench,
• Indirect Lightning is carried out with EM field injection with bi-plate structure.
After checking the functional chain, several measurements configurations have been performed to analyze both the EM impact of the soil and the presence of diode used as peak limiter.

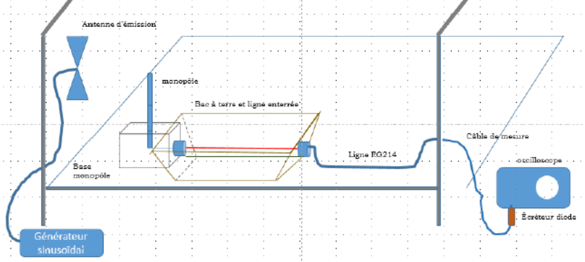

Figure 1. Telecommunication functional chain and its measurement in reception

3. THEORETICAL DECOMPOSITION

The large system of Fig.1 is decomposed into 5 sub-elements. The biconic antenna and its source, the receptive monopole antenna and its enclave base, the buried line (with and without the soil), the two coaxial cables RG214 and the diode used as peak limiter. To generate parasitic signal, two source models are used: BCI injection and Radiated Emission illustrated in Fig.2.

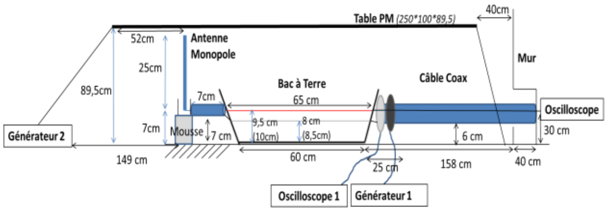

Figure 2. Measurement set-up description

4. LIBRARY OF MODELS

Some analytical and numerical models have been developed to help the EMC engineer in the choice of the best one to study the geometry of the sub-elements.

4.1. Antenna model

Some simple models are included in the library for dealing with low frequency toward the first resonance of the antenna. These are analytical models such as (RC) for short antennas and (RLC) for resonant ones.

For wire antennas, transmission line model is used to represent a large antenna. It is based on the decomposition of the antenna into a series of elementary segments characterized by their RLCG parameters. Analytical Pocklington model is used to represent large monopole and dipole antennas. This is based on a simplification of integral equation for straight wire antenna. For complex geometrical and electrical parameters antenna, MoM or FDTD simulation is used to build an equivalent network based on Vector Fitting theory.

4.2. Cable and buried line

Depending on the length, complexity of the cable cross section or radiated coupling with environment, three cable models will be used: Discretized Transmission Line Model for complex cross section and small length cable. The effect of an external radiated EM aggression is taken into account thanks to an Agrawal model. Chain matrix and Branin models allow not to mesh the longitudinal dimension of the cable [3].

4.3. Equipment and building

Depending on the geometrical and electrical parameters of the cavity, the following models have been developed:
FDFD is used to represent the mode of an arbitrary cavity section. TLM model allows to represent the third dimension of the equivalent short-circuited waveguide. Mode Matching Method allows representing the discontinuities between cavity sections. MoM method could be used to build an equivalent electrical network of the modal representation of the cavity [4].

4.4. Print Circuit Board and Component

To model PCB with MTL, the methods available are: Branin, TLM and Chain matrix. Component and electronic devices are represented by impedance and source equivalent matrix attached with inputs and output ports with the hypothesis of linear behaviour. Local PCB vectorial Near Field Measurement can be used as EM source [5].

4.5. EM Sources models Lightning/BCI/RE

In order to study the effect of a parasitic wave on cables, the developed model answer to two problematics: first we want to study the current induced by an external plane wave on a lightning wave. In this case, different sources functions are defined such as the Hiedler function of the bi-exponential ones. The calculation of the coupling thanks to an Agrawal model (or a Taylor model) on a model of the line as seen above will give access to the parasitic current. In the case on normative bench for example, we inject directly current on a bundle. In this case a Bulk Current Injection model has been defined to impose a current wave locally in the structure.
Regarding Radiated Emission source, plane wave or distributed EM fields are imposed in source components.
At this time, the solver is based on frequency domain resolution. FFT or Laplace transformation are used to transform EM sources, and to check the EM results in both time and frequency domains. It is the case for example with the bi-exponential lightning current source in time and frequency domain illustrated Fig.3.

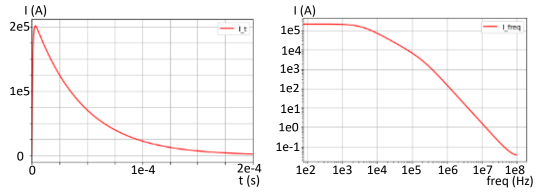

Figure 3. Bi-exponential lightning current source in time and frequency domain

5. APPLICATION ON SYSTEM'S ELEMENTS

Fig.4 shows the measured antenna system. The receptive monopole antenna is connected to a bifilar line going through the planter. Measurements have been realized with and without the soil. A two meters length coaxial cable is connected at a protection diode and at receiver at the exterior of the anechoic chamber.

Figure 4. Test case description: buried line in planter

Each of the system elements is measured and simulated to validate the proposed analytical models based on comparison with measurement and full wave simulation (MoM or FDTD).

5.1. Antenna measurement and simulation validation

Fig.5 shows the S_{11} parameter of the measured 25 cm length monopole antenna. The resonance frequency is identified at 270 MHz.

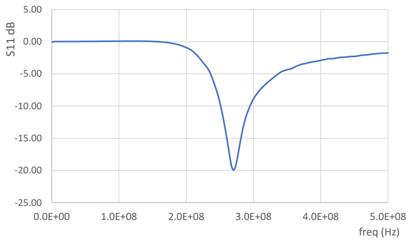

Figure 5. S_{11} parameter for the 25cm monopole Measurement

Fig.6 shows the S_{11} parameter of the monopole simulated with the analytical RLC model and the TLM antenna model. For the two configurations, losses have been activated and desactivated to analyse the losses phenomena impact.

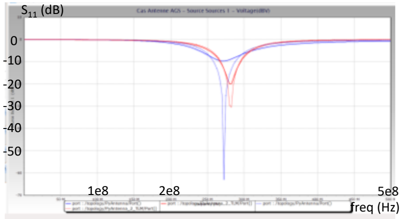

Figure 6. S11 parameter for the 25cm monopole Simulation CAPITOLE-EMC (Analytical and TLM model with and without losses)

Good agreements are obtained between the two proposed models and the measurement.

5.2. Buried line model validation

The planter contains the bifilar line. Fig.7 shows the configuration with and without the soil.

S parameters measurement are compared with simulations with the TLM model and the chain matrix model. Good agreements between measurement and simulation models are observed Fig.8. Soil losses seems varying in term of frequency range. Analytical proposed model allows to evaluate and consider these physical phenomena. Parametric analysis allows identifying the unknown soil material characteristic: epsr=2.8, Tan(teta)=0.15 and conductivity of 30e^{-4} S/m.

Figure 7. Planter with and without the soil bifilar line

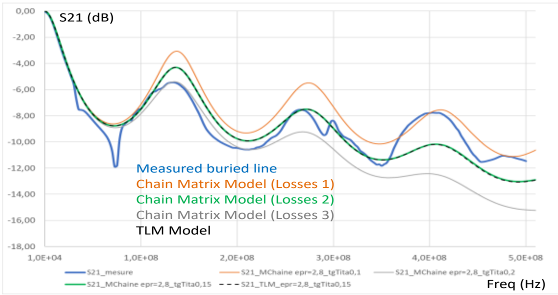

Figure 8. S_{21} parameter for the buried line (Measurement, Chain matrix, TLM Model)

6. APPLICATION: CAPITOLE-EMC

SIMPLEXE project aims to develop a tool that makes it easy to capitalize on the models developed in Python or Matlab languages by the industrial and university community since several years.

The library of models has been developed in an API format in Python language. This allows any EMC specialist to easily add a new analytical or numerical model in the electrical network formalism.

Fig.9 presents the firsts validation tests case which has been measured at AGS described in the first part.

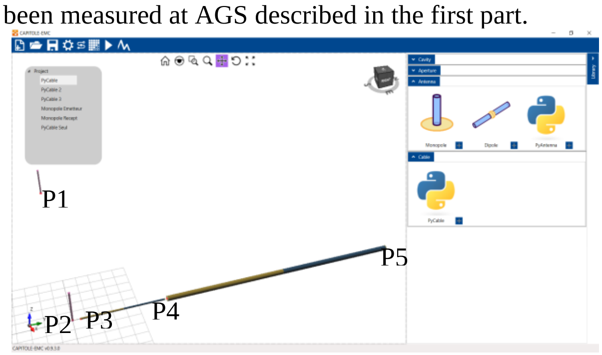

Figure 9. AGS test case visualisation in CAPITOLE-EMC Interface

One emissive antenna is shown Fig.9. The 25 cm length receptive antenna is connected to the 7 cm length coaxial cable at the port 2 noted “P2”. The 67 cm length buried line is connected to the port “P3” and “P4”. The 2 m long coaxial cable is connected to 50 Ohm load at the port “P5”.

Each of the five elements of the system is generated by choosing in the model's library the best adapted analytical model in term of physical phenomena, precision, and computational resources. The models are accessible and improvable since they are coded in Python language.
For the example, two analytical (RLC) models are chosen for the two emissive and receptive antennas.
For the three cables, three different analytical models could be chosen: discretized TLM Model, Chain model and the buried line model depending on the length, the wavelength number, or specific physical phenomena such as the soil losses.
Radiated and conducted coupling are checked to describe easily all the coupling between the five sub-elements of the system illustrated in the two CAPITOLE-EMC boxes:

Figure 10. Radiated and conducted coupling definition

The frequency simulation (20 kHz - 500 MHz) gives the voltages results of Fig.11 with computational simulation time of 4 seconds for 1000 frequency points with standard laptop.

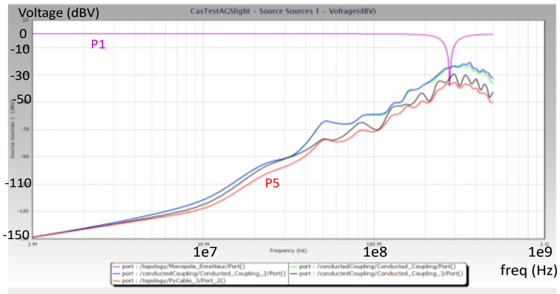

Figure 11. Voltage at the 5 ports of the system

Two simulations are performed to estimate the transfer function of the system with and without soil losses. Fig.12 compares the voltage P5 with and without soil losses.

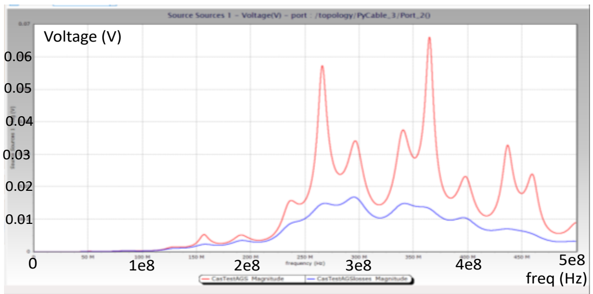

*Figure 12. Capitole-EMC simulation (MoM) of the Transfer Function **with** and **without losses** at P5*

Three sources' signals are simulated to compare with the measurement test:

- Modulated signal for the communication between the two antennas
- Lightning aggression signal (30 A bi-exponential)
- Lightning aggression signal (200 V bi-exponential)

6.1. EM Source 1: Communication signal

Modulated signal current source is analytically defined illustrated Fig.13 in time domain (left) and frequency domain (right).

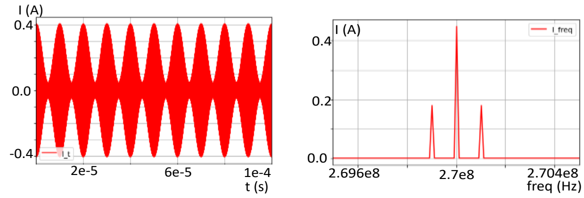

Figure 13. Modulated signal source: time and frequency domain

FFT parameters are : f_{max}=1GHz and tmax=100us. The points number is 49999 from f_{min}=20kHz to 500MHz.

Fig.14 shows at left the transfer function on the system given with CAPITOLE-EMC tool. Total simulation time is 4.0 seconds on laptop.
At right of Fig.14, the current in frequency domain is the combination of the Transfer Function (TF) and the current source signal:

$$P5(f) = Source1\,(f) * TF\,(f) \qquad (1)$$

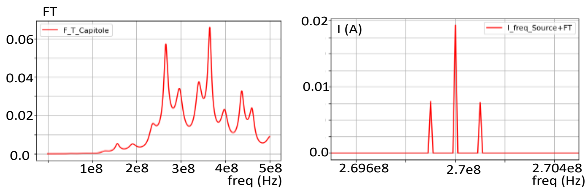

Figure 14. TF and P5(f) without soil losses

Fig.15 shows the same results with the contribution of soil losses.

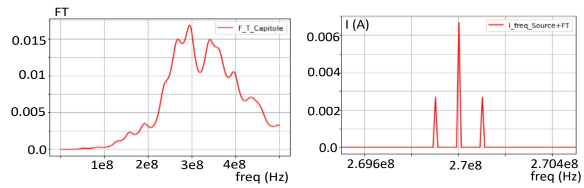

Figure 15. Transfer function and P5(f) with soil losses

Inverse Fourier Transform (IFFT) applied to P5(f) gives the voltage at the extremity of the cable in time domain in Fig.16.

$$P5(t)=IFFT\,(P5(f)) \qquad (2)$$

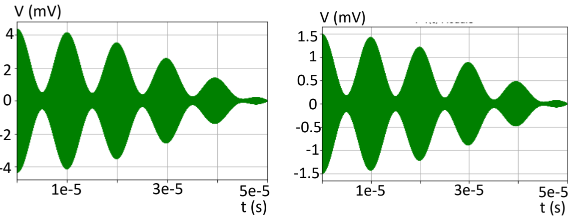

Figure 16. Voltage (mV) at P5 the extremity of the cable, without (left) and with (right) soil losses

Magnitude of the signal at the extremity of the cable is around P5=1.5 mV with soil losses and P5=4.2 mV when soil losses are deactivated.
Total simulation time is 4 seconds for 1000 frequency points (from 10 kHz to 500 MHz).

Measurement campaigns give the voltage at P5=1.2 mV illustrated Fig.17.

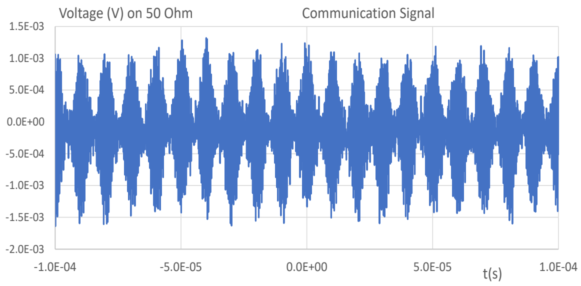

Figure 17. P5 signal Measurement (t_{max}=100us)

Good agreements are obtained between simulation and measurement. Attenuation observed in simulation could be come from numerical problem.

6.2. EM Source 2: Lightning aggression signal (30 A biexponential)

Bi-exponential signal source 2 is defined with the following expression:

It(t) = I0(np.exp(-alpha*t)-np.exp(-beta*t))* (3)
with I_0=30A, Tr = 10e-09s, Tf = 10e-06s

The current signal is illustrated in Fig.18 in time domain (left) and frequency domain (right).

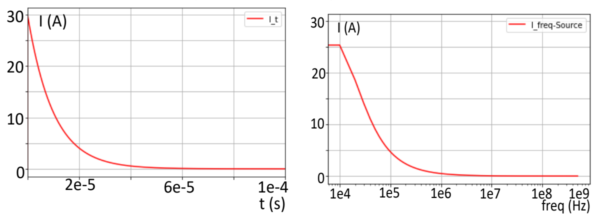

Figure 18. Bi-exponential signal 2 source in time and frequency domain

FFT parameters are : f_{max}=500 MHz and t_{max}=100 us. The points number is 49999 from f_{min}=20 kHz to 500 MHz.

Fig.19 shows at left the transfer function on the system given with CAPITOLE-EMC tool.
At right of Fig.19, the current in frequency domain is the combination of the transfer function and the current source signal:

*P5(f) = Source2 (f) * FT (f)* (4)

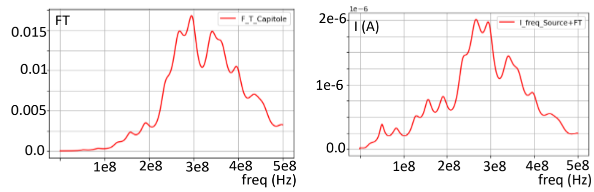

Figure 19. Transfer Function and P5(f) with soil losses

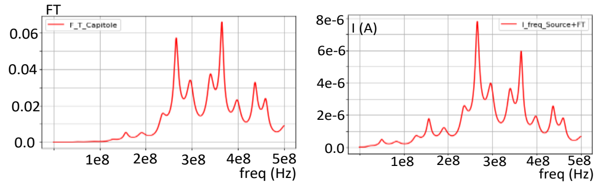

Figure 20. Transfer function and P5(f) without soil losses

Inverse Fourier Transform (IFFT) applied to P5(f) gives the voltage on 50 Ohm at the extremity of the cable in time domain in Fig.21.

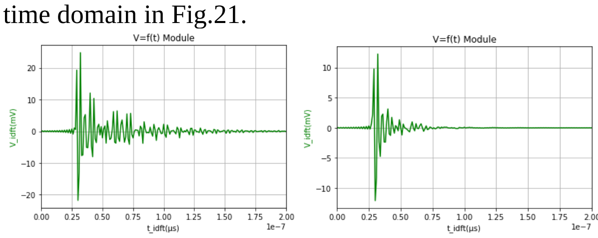

Figure 21. Temporal Voltage (mV) at the extremity of the cable P5 without (left) and with lossy soil (right)

Magnitude simulation of the signal at the extremity of the cable is around P5 = 10 mV with soil losses and P5 = 20 mV when soil losses are deactivated. Measurement with soil losses is in good agreement since P5 = 10 mV shown in Fig.22.

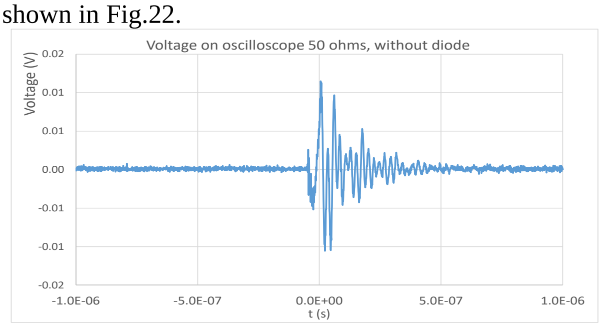

Figure 22. Measurement of Voltage (V) at the extremity of the cable P5 with soil losses

6.3. EM Source 3: Lightning aggression signal (200 V biexponential)

Bi-exponential signal source 3 is defined with the

following expression:
$V(t) = V0*(np.exp(-alpha*t)-np.exp(-beta*t))$ (5)
with V_0=200V, Tr = 10e-09s, Tf = 10e-06s

The voltage signal is illustrated in Fig.23 in time domain (left) and frequency domain (right).

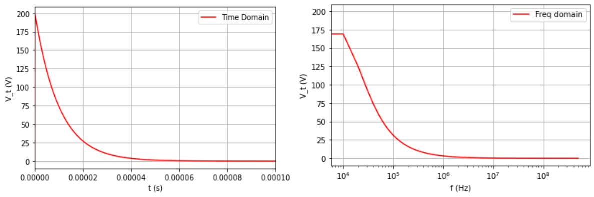

Figure 23. Bi-exponential voltage signal source 3 in time and frequency domain

Fig.24 shows at right the voltage in frequency domain of the combination of the transfer function and the voltage source signal:

$$P5(f) = Source2(f) * FT(f) \quad (6)$$

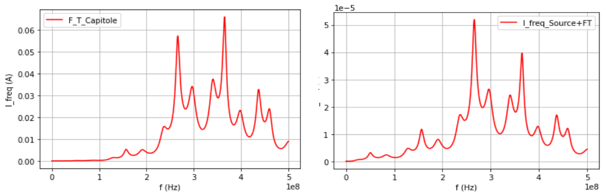

Figure 24. Transfer Function without lossy soil and Voltage Source Signal 3 (f)

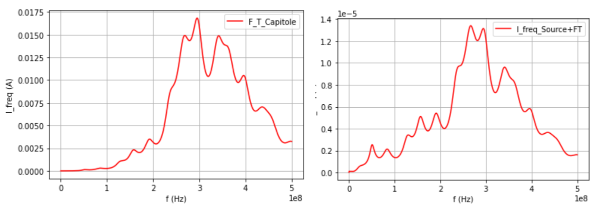

Figure 25. Transfer Function with lossy soil and Voltage Source Signal 3 (f)

Inverse Fourier Transform (IFFT) applied to P5(f) gives the voltage on 50 Ohm at the extremity of the cable in time domain in Fig.26.

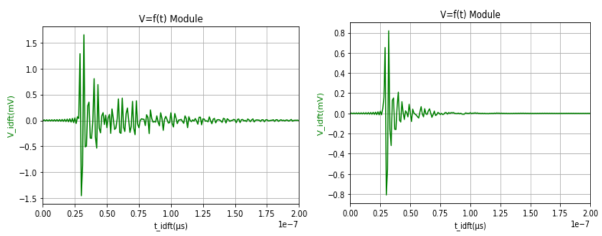

Figure 26. Voltage (mV) at the extremity of the cable P5 without and with lossy soil (on 50 Ohm)

P5 voltage is 1.5 V without lossy soil in accordance with TEMSI-FD simulation (FDTD) and measurement results shown Fig.27.

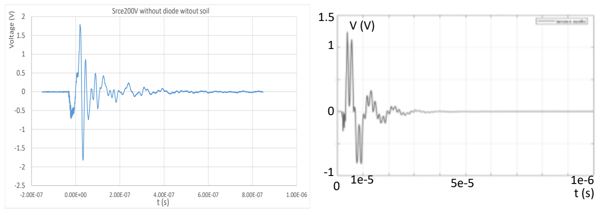

Figure 27. Reference: Measurement (left) and TEMSI-FD (right) simulation of the system without lossy soil

7. CONCLUSION

In this paper we have described an original method based on the tensorial analysis of networks formalism. This method allows the modeling of large systems submitted to parasitic electromagnetic waves based on electrical network representation.
The objective was to develop software and a friendly interface to quickly construct the equivalent model of a complex system and to solve the problem without huge computational resources. This has been made by the construction of a database containing an important number of models for modeling the different elements of a system. Then they can be easily connected together. A typical example where experimentation has been made for the validation of the different parts of the system. The comparisons theory and experimentation clearly validate our method.
One of the main advantages of our approach is that increasing the length of the antennas, the transmission lines do not change the computational effort (4 seconds). Moreover, we must note that the models take into account realistic parameters like the skin effect.
Some models are still to be developed particularly for taking protection components such diodes that are nonlinear system. This work is in progress.

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