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Modelling of Electronic Devices using Radial Basis Functions for EMC Evaluation

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Abstract— In this paper a black-box identification technique based on the radial basis functions (RBF) is used in developing global dynamic behavioural models of electronic devices from measured transient responses. RBF allow to reproduce a non-linear dynamic model of the device under modelling (DUM) automatically taking into account all the physical effects relating input and output data, from measured waveform only: no knowledge of the internal structure is needed. Suitable parameters have to be evaluated by using selected voltage/current identification signals that allow to build up the global model of the DUM. The development of such global model constitutes the first step for electromagnetic compatibility (EMC) compliance in high performance electronic systems for information and communication technology and for industrial applications. In fact, due to the high complexity of such interconnected systems, EMC compliance can be obtained since the design stage only if the whole system is firstly scattered in low complexity sub-systems, opportunely modeled and then composed by the system physical interconnections to obtain the original apparatus. Global model is firstly obtained for logical I/O port and the validation is obtained by comparison with SPICE simulations. Original application related to single electronic component such as bipolar junction transistor is also reported and validated by comparing simulation results with measured data.

Index Terms—RBF, black box models, electromagnetic compatibility

INTRODUCTION

Electromagnetic compatibility (EMC) evaluation in high-performance electronic systems for information and communication technology (ICT) and for industrial applications, is extremely difficult because of the high complexity of the system and the wide frequency range of the involved signals. Otherwise, EMC compliance analysis has to be carried out since the design stage in order to obtain the correct electromagnetic behavior of the system at low cost without the use of *a posteriori* high expensive corrective strategies to be adopted for the built system. On the other hand, EMC can be obtained only if the whole system is firstly scattered in low complexity sub-systems, opportunely modeled and then composed by the system physical interconnections to obtain the original apparatus. It is important to underline that these interconnections constitute the most important source of electromagnetic interference (EMI): thus the interconnections, with ever more complicated structure, have to be also opportunely modelled and assembled with the I/O sub-models in order to simulate the whole system. Even if such an approach could lead to accurate analysis, some aspects are still to be opportunely investigated and the global modeling techniques of such systems stimulate a growing research interest in the scientific community [1], [2], [3]. The difficulties that still arise in using black box identification technique for high performance electronic devices can be summarized as follows: high request of computational resources; direct comprehension of the physical phenomenon which is at the basis of the system operations and the following model identification; the model should be valid for the whole frequency range of the involved signals; non linearity; complex shape interconnections with size comparable or less to the signal minimum wavelength; noise sources.

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In this paper a black-box identification technique [4] based on the radial basis functions (RBF) [5] is presented in developing global dynamic behavioural models of electronic devices from measured transient responses. RBF allow to reproduce a non-linear dynamic model of the device under modelling (DUM) automatically taking into account all the physical effects relating input and output data, from measured waveform only: no knowledge of the internal structure is needed. Suitable parameters have to be evaluated by using selected voltage/current identification signals that allow to build up the global model of the DUM. Global model is firstly obtained for a logical port, in a way similar to that obtained in [1], [2], and the validation is obtained by comparison with SPICE simulations. Original application related to single electronic component such as a bipolar junction transistor (BJT) is also reported and validated by comparing simulation results with measured data. The use of the BJT as a logic state component is common in industrial applications for electronic converter in electrical motor drive, and the possibility of its simulation as a black box and the subsequent assembly with the other apparatus constitutes, in authors opinion, a challenging way to asses EMC since the design stage, in conjunction with the simulation of the physical interconnections.

USE OF RADIAL BASIS FUNCTIONS FOR ELECTRONIC DEVICE MODELING

In order to explain the procedure used to model an electronic device it is useful to firstly refer to a logical port, following the way depicted in [1]-[2]. It is possible to express the port electric non-linear behavior as a function of the input voltage and the output current:

$$F(i,v)=0 \tag{1}$$

The target is to describe the I/O behavior by a parametric black box function. This function can be represented as follows [1], [2]:

$$y(k)=g(\vec{x}(k),\Theta) \tag{2}$$

where the quantity Θ collects the model parameters, and the function g maps the present and past samples of the input voltage and the past samples of the output current into the present sample of the output current. The vector $\vec{x}$ is called regression vector, since it contains $2r$ past samples and the actual input:

$$\vec{x}=[u(k),u(k-1),...,u(k-r),y(k-1),...,y(k-r)]^T \tag{3}$$

r is the dynamic order of the regression vector.

At this point, it is possible to express (1) as the sum of non-linear functions of the regression vector:

$$G(x,\lambda)=\sum_{i=1}^{L}\lambda_i f_i(\vec{x}) \tag{4}$$

where $f(\vec{x})$ is a basis function, obtained from a single mother function by varying dilation and position (both nonlinear parameters), λ_i is a coefficient and L is the total number of the basis functions used in building the model.

According to what reported in [1] and [2], the selected basis function is the Gaussian one:

$$f(x)=exp\left(\frac{|x-c|}{\beta}\right)^2 \tag{5}$$

in which c defines the position and β defines the dilation of the function.

The next step is the determination of the elements of Θ, i.e. the parameters of the basis function in the model:

$$\Theta=\left[\lambda_1,...,\lambda_L;c_1^{iT},c_1^0,c_1^{vT},...,c_L^{iT},c_L^0,c_L^{vT};\beta\right]^T \tag{6}$$

These parameters represent the centre and the dilations of the *L* basis functions.

As for the centre, it has been shown in [1], [2] that, since the radial basis function are weakly sensitive to the position and dilation parameters, it is possible to select them *a priori* and then estimate only the coefficients λ_i by a least square problem solution [6].

The dilations are chosen in order to allow a good overlapping of the single functions.

The internal states of the logic port, which account for the output state (high, low) are not measurable. In order to estimate the model by external measures only, a two-piece model representation is used [1], [2]. In this way the switch between the two logic states is represented by the switching between the two sub-models:

$$i(k) = w_1 i_1(k) + w_2 i_2(k) \tag{7}$$

where $i(k)$ is the actual output current, w_1 and w_2 are time-varying coefficients accounting for state switching, $i_1(k)$ and $i_2(k)$ are the RBF sub-models describing the port behavior in the different logic states.

Each sub-model can be defined as follows:

$$i_1(k) = f_1\left(\Theta; \vec{x}_i, v^k, \vec{x}_v; k\right) = \sum_{i=1}^{L} \lambda_l \psi_l(k-1) exp\left\{ - \frac{\left(v^k - c_l^0\right)^2}{2\beta^2} \right\} \tag{8}$$

where:

$$\psi_l(k-1) = exp\left\{ - \frac{\left\| \vec{x}_i^{k-1} - c_l^i \right\|^2 + \left\| \vec{x}_v^{k-1} - c_l^v \right\|^2}{2\beta^2} \right\} \tag{9}$$

The determination of the parameters λ_i is carried out by a typical black box system identification [4]. A multilevel voltage waveform is enforced to the input port while it is forced in a fixed logic state (high, low) and the related current waveform is sampled at the output. A typical input waveform is shown in fig.1. The over-voltage Δ is allowed by the port constructor, V_{ss} and V_{dd} are the limits of the operation voltage range. Such a signal is selected in order to excite every dynamic behaviour of the DUM.

Once the output signal is recorded, the dynamic order *r* of the regression vector (i.e., how many past samples are needed to obtain a good matching between the model output and the recorded measure of the output signal) is determined *a priori*. Again, in [1], [2] it has been shown that, for the most common logic ports, the dynamic order *r* is 1-2 and the number of the basis for each sub-model is in the range {5-20}.
For a model composed by *L=1,2,3…* basis function with an a priori stated *r*, the following steps are repeated:

- a basis function is added to a model with *L-1* basis. The centre of the added basis is the one giving rise to the largest decrease of the error;
- if the mean square error is below the desired value, the process is terminated. Otherwise, the previous step is repeated until the further addiction of a radial basis function does not improve the model output.

The last step is the identification of w_1 and w_2. These are obtained by linear inversion of (7), i.e.:

$$\begin{bmatrix} w_1(k) \\ w_2(k) \end{bmatrix} = \begin{bmatrix} i_1(k) & i_2(k) \\ i_1(k) & i_2(k) \end{bmatrix}^{-1} \begin{bmatrix} i_a(k) \\ i_b(k) \end{bmatrix} \tag{10}$$

where $\{i_a, v_a\}$ and $\{i_b, v_b\}$ are switching signals recorded while two different loads are connected to the output and the DUM is forced to switch from high logic state to low and back to high state. The

loads used are those recommended by IBIS [7]: load (a) is a resistor and load (b) is a series connection of a resistor and a V_{dd} voltage source.

VALIDATION AND APPLICATION RESULTS

In order to evaluate the precision of the proposed model, an application has been carried out. A simple circuit (fig. 2) containing a NAND gate of an IC7400 has been simulated in SPICE and the results have been compared with the RBF model of the NAND gate. V1 is the waveform voltage generator, V2 is used to force the DUM in a logic state (high, low), R1 is the resistive load represented by a 50 Ω resistance. C1 and C2 are the capacitance simulating the passive voltage probes of a virtual oscilloscope. This addiction has been made to represent as close as possible a real measure. In fact, on a real measure, the current should be sampled as the voltage drop at the pins of R1 divided by R1 itself. The voltage waveform generated by V1 and the resulting current measured on R1 are shown in fig. 3 and 4. The last step is the evaluation of w_1 and w_2. V1 has been replaced with a 50 ohm resistor and a series connection of a 50 ohm resistor and a 1.8 V voltage source as load (a) and load (b) respectively, and V2 has been used to force the DUM to switch from low state to high state and back to low. Fig.5 and fig. 6 show the identification signals when the DUM connected to load (a). For the validation of the model, a comparison between the SPICE simulation and the RBF model is carried out. The DUM is connected to a R-C series load and is driven by three pulses by V2. The results are shown in fig 7.

In order to apply the RBF modelling procedure to a real device used in common in industrial applications for electronic converter in electrical motor drive, the circuit shown in fig. 8 has been setting up. The DUM is a BD139, a BJT used in power controls. The electric scheme of the circuit is reported in fig. 9. V1 is a controlled voltage generator ISO-TECH IPS 2303DD. It is used to drive the DUM by polarizing the base. When the 5V voltage is supplied, the DUM is in high state and the device acts as a closed switch. When the generator is turned off, the DUM is in low state and no current can circulate between emitter and collector. V2 is a programmable waveform voltage generator Agilent 33120 A and it is used to generate the identification signal shown in fig. 10. The current output when the DUM is driven in high state is shown in fig. 11.

Current and voltage data are collected by a Yokogawa DL1540 digital oscilloscope with sampling time equal to 100 ns. By driving the DUM at first in high state, then in low state, the two current outputs are sampled. Then, a model for each logic state is built up. Each model is composed by 5 RBF and the dimension of the regression vector is 2, i.e. to calculate the actual output, the knowledge of two previous values of the input and of the output are required.

After having calculated the time-varying coefficients w_1 and w_2, the RBF model is validated by connecting the DUM with a R-C parallel load and by driving it with a single pulse with a time period of 1 ms and duty-cycle 0.5. The comparison between measured and computed results are reported in fig. 12.

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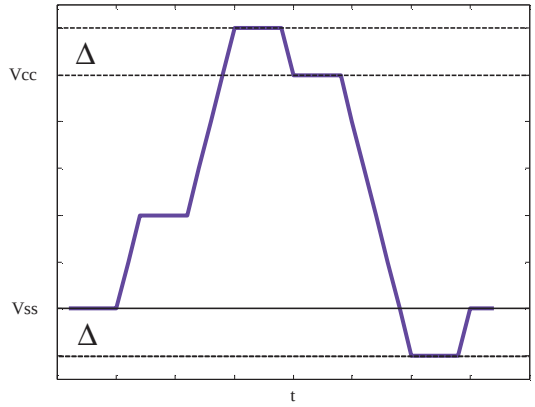


Fig.1. Input signal used for the identification of the model parameters.

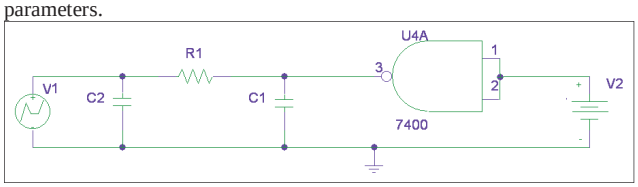


Fig.2. Spice circuit used for the validation of the proposed model.

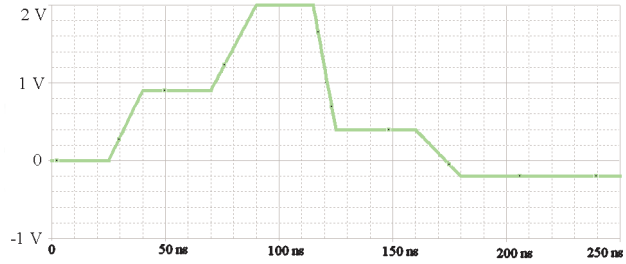


Fig.3. Voltage waveform input signal for the estimation of the sub-models.

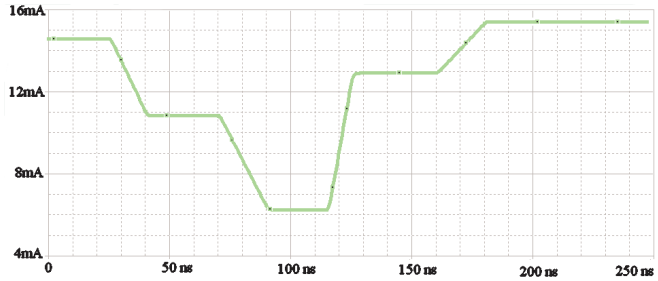


Fig.4. Current waveform output signal for the estimation of the sub-model i_1.

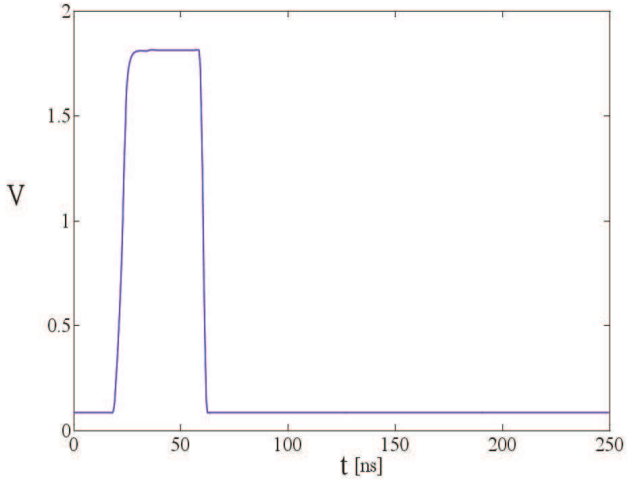


Fig.5. Input voltage signal for the estimation of w_1 and w_2 while the DUM is connected to load (a).

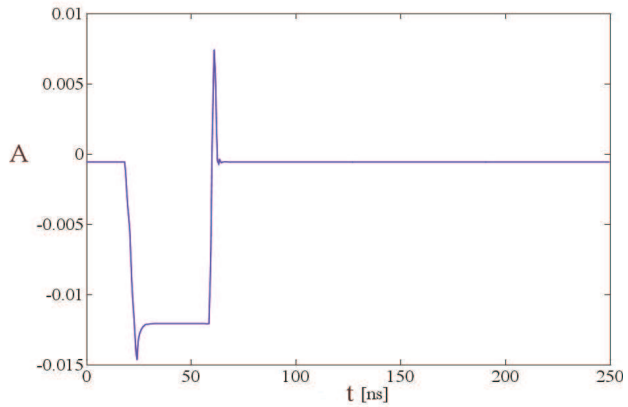


Fig.6. Current output signal for the estimation of w_1 and w_2 while the DUM is connected to load (a).

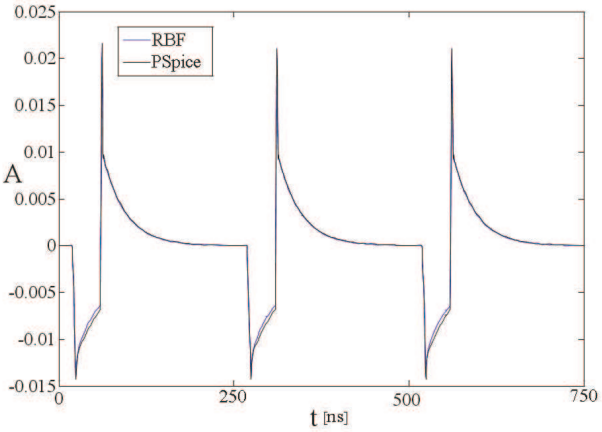


Fig.7. Current output signal for the validation of the model. The DUM is driven by 3 pulses with duty-cicle 0.2 and a time period of 250 ns.

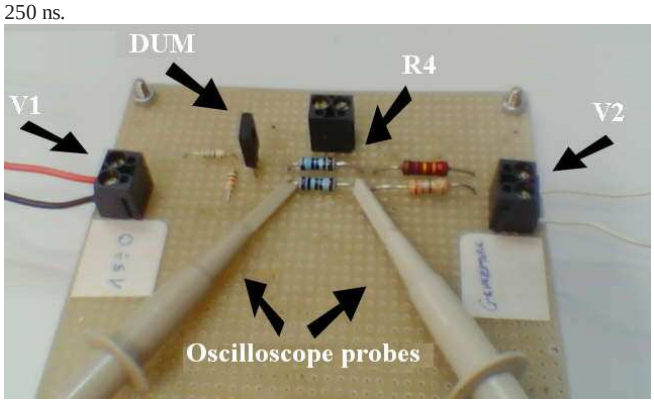


Fig.8. Identification circuit for the modelling of a BD139 bipolar junction transistor.

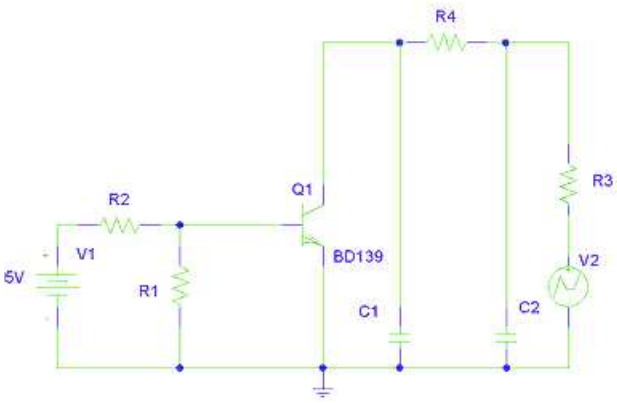


Fig.9. Electric scheme of the circuit shown in fig.8. C_1 and C_2 represent the capacities introduced by the oscilloscope probes.

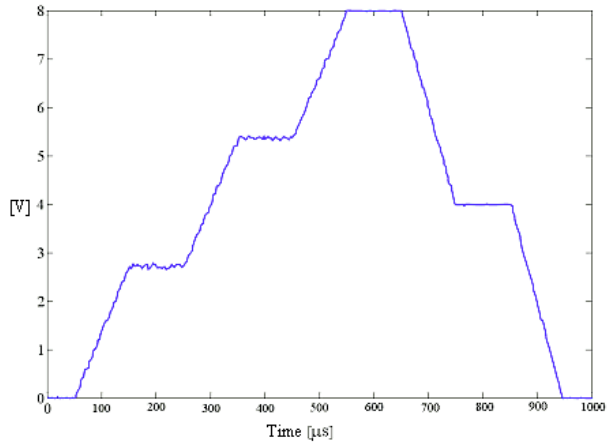


Fig.10. Voltage waveform generated by V2.

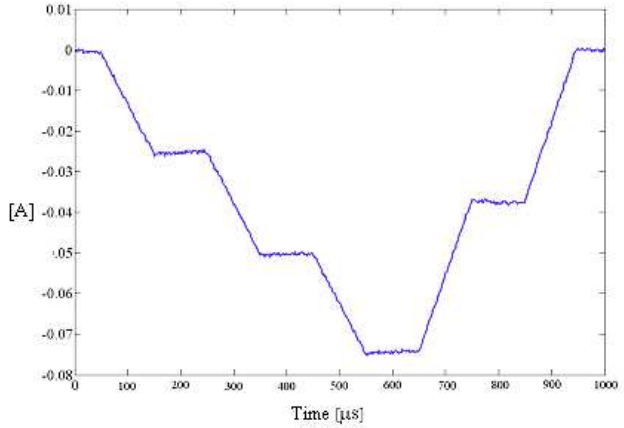


Fig.11. Current output when the DUM is driven in HIGH state.

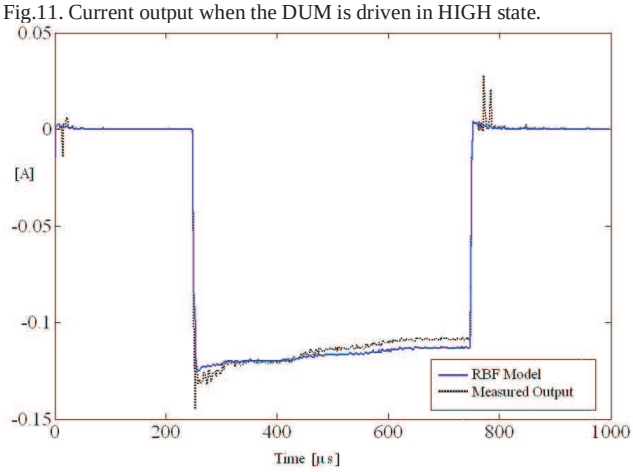


Fig.12. Validation of the RBF model for the BD139 BJT.