Zbornik radova XLVI Konf za ETRAN, Banja Vrućica – Teslić, 4-7 juna 2002, tom I
Proc. XLVI ETRAN Conference, Banja Vrućica – Teslić, June 4-7, 2002, Vol. I

ANN APPLICATION IN MODELLING OF A/D INTERFACES FOR MIXED-MODE BEHAVIOURAL SIMULATION

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Abstract: *Artificial neural networks are applied for modelling the input circuits of the digital part at the analogue/digital interface in mixed-mode circuits. The generalization property of the neural networks is exploited to apply the models in a set of previously unknown situations. It is also shown that mixed-level analogue behavioural simulation is enabled if the same modelling concept is applied.*

1. INTRODUCTION

The design of electronic and telecommunication integrated circuits is unavoidably faced with simulation of analogue subsystems of ever rising complexity thereby building more complex mixed-signal systems containing both analogue and digital parts. Design of such systems needs simulation tools that perform fast and accurate in the same time. Main obstacle to this requirement is related to the difficulties in high level modelling of the analogue part and accurately enough modelling of the digital-analogue (D/A) and analogue-digital (A/D) interfaces being frequently encountered in such systems [1,2]. In fact at the (D/A) interface one needs to model the output circuit of the digital part in order to enable electrical excitation for the analogue load. In the opposite case, at the (A/D) interface, we need to model the input impedance of the digital part in order to establish conditions for computation of the voltage und current at the interface. Having in mind that the simulation is performed in the time domain, the fact that we are dealing with mixed-level simulation, and the complexity and non-linearity of the circuits involved, one generally apply behavioural modelling for these purposes. We will consider here the analogue mixed-level behavioural modelling as a special case of the behavioural modelling of mixed-signal systems and following that we will speak about the latter one only.

Considering Fig. 1 we may have two distinct situations. First, at the D/A interface we need an electrical circuit to model the output of the digital part performing D/A signal conversion and electrical compatibility in the same time. Among the solutions available in the literature we will mention [3,4] where time-varying resistors are used, and [5,6] where a procedure was proposed predominantly oriented to the resistive part of the non-linear output impedance of the model. We have no alternative solution for this problem based on artificial neural networks (ANN) at the moment but, hopefully, it will be obtained soon. Second, for the A/D interface, the input impedance of the digital part is to be modelled. Usually, for MOS circuits, a linear capacitor is used for this purpose in the literature. We will show here that the input capacitance is highly non-linear asking for a more sophisticated modelling procedure. A method will be described here based on ANNs for this purpose. The basic idea for this solution was first applied for non-linear impedance modelling [7] based on the results reported in [8].

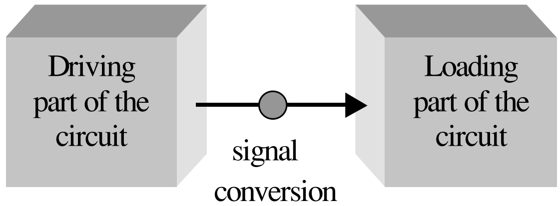

Fig. 1. *The interface*

After the first application of artificial neural networks (ANN) for modelling electronic components [9] it became clear that this concept may be successfully used for modelling dynamics, too. In [10] the dynamics in a micro-electro-magneto-mechanical actuator was modelled by taking advantage of the fact that the dynamic and the resistive properties could be expressed separately. Full non-linear dynamic modelling using ANN was described in [11], the approximation, however, being performed in the frequency domain using direct and inverse Fourier transform repeatedly. Here we propose, for the first time, artificial neural networks to be used for behavioural modelling of the digital input with modelling performed in the time domain.

2. DESCRIPTION OF AND VERIFICATION OF THE MODEL

In order to get a full picture of the problem under consideration we will first describe the circuit elements arising in a simple circuit such as an inverter is. It is depicted in Fig. 2. As we can see along with the non-linear resistive transistors we have six non-linear capacitors (three per transistor) [12]. Two of the capacitors are connected at the feed-back and feed-forward path so behaving as Miller capacitors, the gain, however, being non-linear function of the input signal. This is illustrated in Fig. 3 where the derivative of the transfer characteristic [$v_{out}(v_{in})$] is shown acting as the inverter's gain. According to this the input impedance of the inverter (representing, without loss of generality, all circuits produced in CMOS technology) is a non-linear capacitor depending on the input signal. The function, however, is not known. This is why ANNs are a feasible solution of the modelling problem of the input circuit of MOS building blocks.

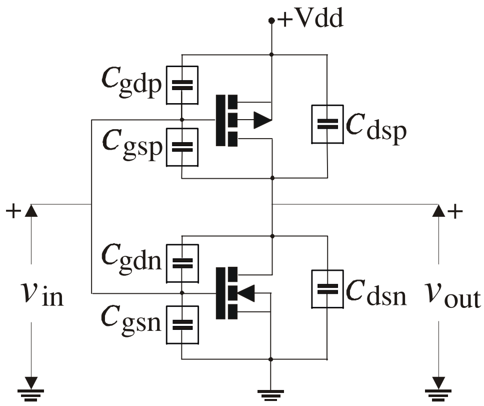

Fig. 2. *CMOS inverter with non-linear capacitances shown*

The problem may be stated as follows. Find the topology, the complexity, and the parameter values of an ANN behaving equally as the input circuit of the digital part at the A/D interface. To solve this, electrical simulation of the digital part is to be performed first. This simulation should be done in the cell characterization phase of the digital cell design. A specific problem in this phase is the choice of the exciting signal. Namely, a signal should be chosen such that to enable modelling using ANN in the time domain. As shown in [7,8] a chirp signal is convenient for this purpose. Here, having in mind the capacitive nature of the input circuit, small variation of the frequency will suffice. In fact, no variation was applied. The signal is depicted in Fig. 4.

The simulation results, input voltage as a function of time, for the inverter from Fig. 2 are depicted in Fig. 5. It is denoted by "original". Here sinusoidal current excitation of 1.8 mA amplitude and 200 MHz was used to obtain the voltage response shown. Current voltage pairs from this simulation were used to train the ANN the topology of which is depicted in Fig. 6 [7,8]. It is a time-delayed recurrent neural network. The training procedure is practically the same as in [13]. The first results are shown in Fig. 5. Here output voltage waveform of the model is shown together with the original response used for training. Excellent agreement of the responses was obtained even though very simple excitation was used.

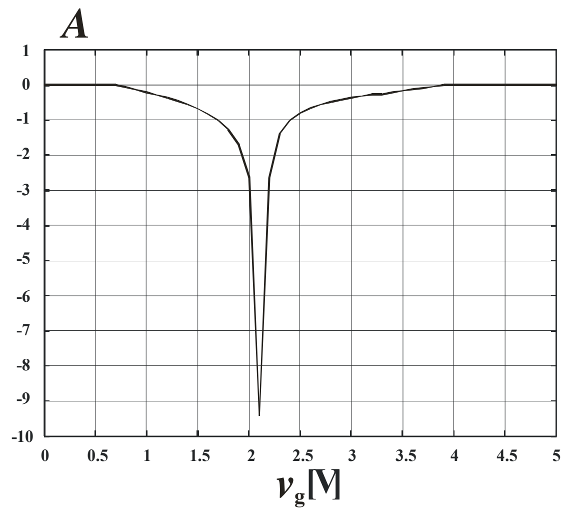

Fig. 3. *The (low frequency) voltage gain (A) of the inverter as a function of the input signal (v_g)*

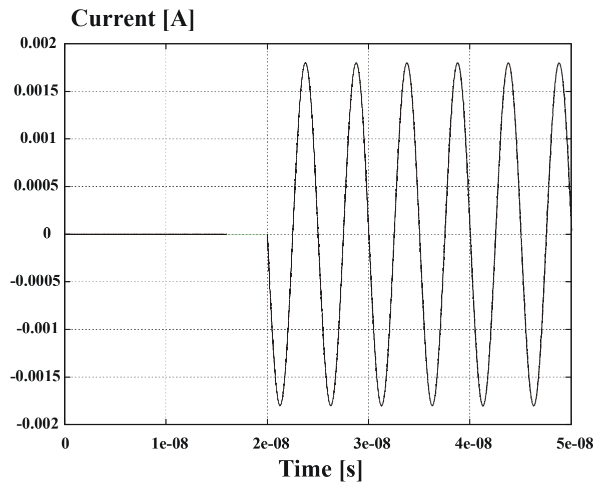

Fig. 4. *Current waveform used for generation of the input-impedance time-domain behavioural model (f=200 MHz)*

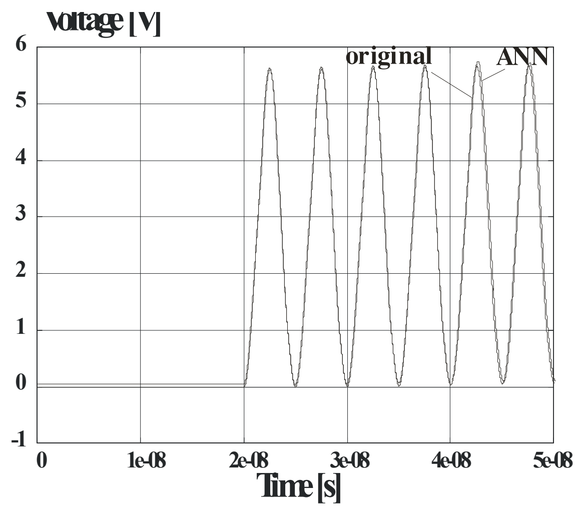

Fig. 5. *Response (voltage) at the inverter input obtained for the excitation of Fig. 4. "original" means circuit simulation of the inverter of Fig. 2, while "ANN" stands for the response of the model*

Table 1. Weights and thresholds in the ANN

No.	Hidden-layer neurons (First figure stands for the input neuron)	Output neuron (First figure stands for the hidden neuron)
1	$w^1(1,1) = -1.15618$ $w^1(2,1) = 0.303841$ $w^1(3,1) = 0.801999$ $w^1(4,1) = -0.655468$ $w^1(5,1) = -0.112933$ $\theta^1_1 = 1.69522$	$w^2(1,1) = -1.24339$ $w^2(2,1) = 1.41557$ $w^2(3,1) = -1.98177$ $w^2(4,1) = -2.18655$ $\theta^2_1 = 2.91066$
2	$w^1(1,2) = 0.138613$ $w^1(2,2) = -1.16098$ $w^1(3,2) = 1.01521$ $w^1(4,2) = -0.128065$ $w^1(5,2) = 0.915597$ $\theta^1_2 = -0.890606$	
3	$w^1(1,3) = -0.537022$ $w^1(2,3) = 1.64986$ $w^1(3,3) = -1.1164$ $w^1(4,3) = -2.64625$ $w^1(5,3) = 1.49825$ $\theta^1_3 = -1.15733$	
4	$w^1(1,4) = -1.13048$ $w^1(2,4) = 1.87005$ $w^1(3,4) = -0.716303$ $w^1(4,4) = -3.13684$ $w^1(5,4) = 2.4126$ $\theta^1_4 = 1.53233$	

For the example used here, five input, four hidden, and one output neuron are incorporated. Note the hidden neuron have sigmoidal while the output neuron has linear activation function. Table 1 contains the weights and the thresholds of the neurons.

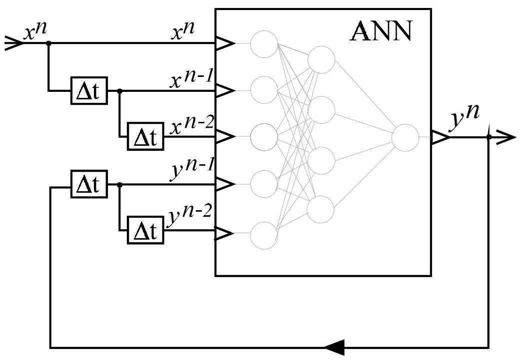

Fig. 6. The artificial neural network used for modelling example

In order to show the quality of the approximation procedure and the generalization capabilities of the ANN a new example circuit is constructed. It consists of two inverters. The first one (the driver) is considered analogue exactly the same as in Fig. 2. The second (the load) is considered digital. The whole is depicted in Fig. 7. *The voltage at the A/D interface (v_1) is of interest.* Later, during the simulation, it will be compared with thresholds in order to establish the logic level of the input signal to the logic part. In order to get it SPICE-like simulation is needed with the digital part substituted by its electronic circuit equivalent. Here the need for modelling becomes apparent. For model verification purpose, however, the digital part is substituted by its electrical schematic.

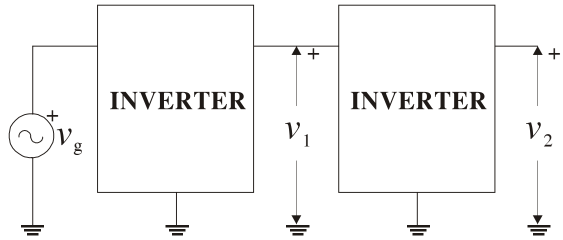

Fig. 7. *Original circuit used for verification (left inverter is part of the analogue circuit while the right one is considered digital)*

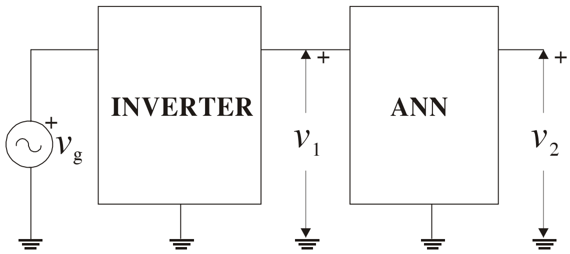

Fig. 8. *Inverter (analogue) loaded by ANN behavioural model used for verification of the model*

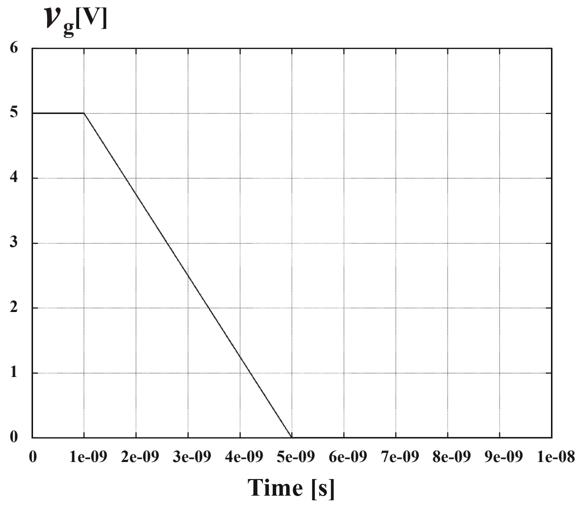

Fig. 9. *New exciting signal*

Application of the model means substitution of ANN at the place of the digital part as shown in Fig. 8. This circuit is all analogue but the ANN is not a circuit element. Consequently one needs a behavioural simulator to exercise such model [14].

The generalization property is verified by use a signal not known to the ANN beforehand. Having in mind the excitation of Fig. 4, and the real signals arising in digital circuits, we have chosen the ramp signal shown in Fig. 9.

The comparison of simulation of the circuits of Fig. 7 and Fig. 8 shown on Fig 10 reveals the success in the modelling and approves the feasibility of the idea.

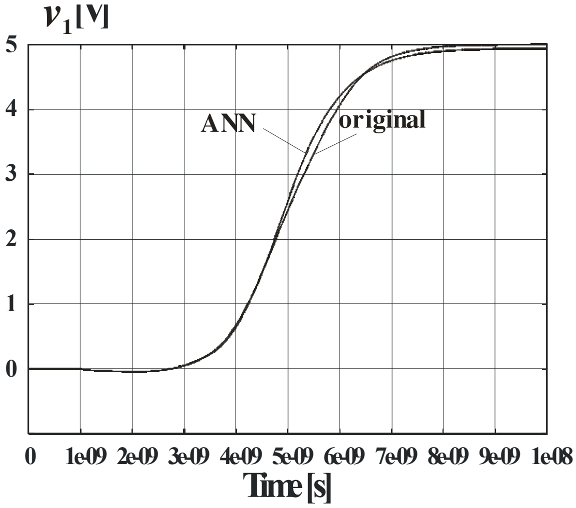

Fig.10. *Response at the interface of two inverters of Fig. 7 obtained by circuit simulation with digital part substituted by the complete circuit of the inverter (denoted by "original") and digital part substituted by ANN as in Fig. 8 (denoted by "ANN")*

3. CONCLUSION

New ANN approach to the modelling of the A/D interface in mixed-mode circuit is described. The generalization property of the ANN is demonstrated by using input signals not known during training. The model is exercised in an electrical environment fully different to the one used in training. Even these first results show the effectiveness and applicability of the idea proposed.

4. REFERENCES

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PRIMENA VEŠTAČKIH NEURONSKIH MREŽA ZA MODELOVANJE A/D SPREGE PRI FUNKCIONALNOJ SIMULACIJI KOLA SA MEŠOVITIM SIGNALIMA

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