Twenty years of ANN research and application in LEDA

Vančo Litovski

Abstract – This is to overview the research results in The Laboratory for Electronic Design Automation (LEDA) at the University of Niš, in the field of application of Artificial Neural Networks in electronic design. In all, 49 papers were published related to ANN application and theory of learning while 21 authors were involved six of them from outside of LEDA.

Keywords – Artificial neural networks, electronic design, modelling, testing, diagnosis, prediction.

I. Introduction

It all started with the invitation by Prof. Đuro Koruga to the International Summer School and Workshop on Neurocomputing Theory and Application that took place in Dubrovnik on September 1-10, 1990.

TABLE 1
CHRONOLOGY

Date	Event/person
November, 1990	The First International neurocomputing symposium (INS) organized
August, 1992	The MOS transistor model was published (Rađenović, J., Mrčarica, Ž., Milenković, S., and Zografski, Z.)
May, 1994	Implementation to channel routing (Ranđelović, Z.)
September, 1995	The second order synapse was published (Milenković, S.,)
September, 1995	Implementation to pattern recognition (Milenković S.,)
June, 1996	Simulated annealing learning based on noise signals was published (Milenković, S., Obradović, Z., and Risojević, V.,)
February, 1997	Implementation to automation of the microelectromechanical systems assembly (Rađenović, J., Mrčarica)
August, 1997	Implementation to electro-magneto-mechanical systems modelling and simulation (Mrčarica, Ž., and Ilić, T.,)
September, 2000	Implementation to modelling of two terminal dynamic linear circuits (Zarković, K., Ilić, T.)
September, 2002 June, 2003	Implementation to modelling of two terminal resistive nonlinear circuits – The double hook attractor and the Josephson junction - (Andrejević, M., and Stojilković, S.,)
July, 2002	Implementation to modelling of two terminal dynamic nonlinear circuits (Andrejević, M.)
September, 2003	Implementation to modelling the A/D and D/A interface (Andrejević, M., Damper, R.I., and Petković, P.)
May, 2004	Implementation to analogue diagnosis (Andrejević, M., and Zwolinski, M.)
December, 2004	Implementation to testing of MEMS (Andrejević, M., and Zwolinski, M.)
June, 2006	Implementation to mixed signal diagnosis (Andrejević, M., and Zwolinski, M.)
June, 2007	Implementation to environmental prediction (Milojković, J.)
June, 2009	Implementation to prediction in microelectronics (Milojković, J.)
September, 2009	Implementation to prediction in power consumption (Milojković, J.)

After that we organized the First International neurocomputing symposium (INS) that took part at The Faculty of Electronic Engineering on November 1990. It was organized by LEDA. Participants from several countries were present with all papers invited. This event, while modest in scope and from the point of number of participants, became the main milestone in the development of research in the area. Among other, but probably the most important, was the present done by Dr Zlatko Zografski. He delivered to us for free his programs for feed-forward ANN learning (LEARNNET) and running (RUNNET). These programs are successfully used in LEDA all the time. Table 1 gives the chronology of the developments related to ANN research at LEDA.

Most of the implementation of the ANNs at the time were oriented to decision making and pattern recognition and in order for that scientific discipline to survive in LEDA we needed some application in electronic design. One is to mention that we already had implementations of rule based artificial intelligence methods (the competitor of the ANNs at the time) for integrated circuits cell placement compaction.

Vančo Litovski is with the Department of Electronics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia,
E-mail: vanco.litovski@elfak.ni.ac.rs.

II. HISTORY

Following the claim that ANN can approximate any mapping, what is called generalization property, we came to the idea to model the MOS transistor. At the time the model implemented in SPICE suffered from important problems that were consequence of discontinuous derivatives of the transistor's characteristic at the transition between the linear and the saturation region. SPICE is Newthon-Raphson based program and needs continuous derivatives to maintain convergence. The ANN implementation developed did not suffer from that problem. The output characteristics obtained are given in Fig. 1.

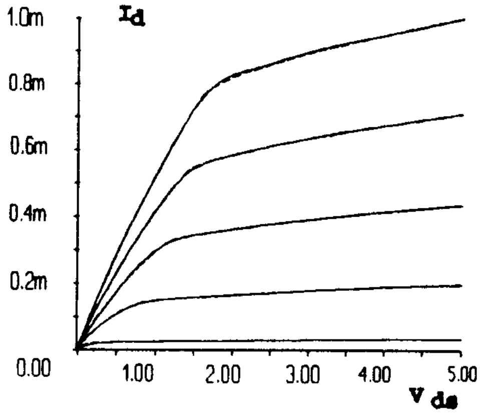


Figure 1. MOS transistor's output characteristics modelled by ANN

Fig . 2 and Fig. 3 represent the output current derivative with respect to the output and input voltages, respectively, for the ANN and SPICE model. The ANN solution solved the problem but not only that. It gave us courage to continue in the subject.

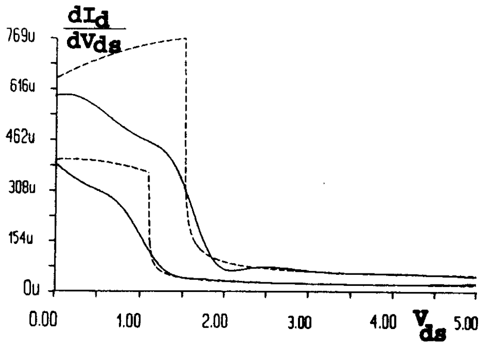


Figure 2. Output conductance of a MOS transistor obtained from the SPICE and ANN model

Theoretical research both in ANN architectures and in learning methods started. As a result we got the second order synapse. There are claims that we were the first to introduce second order synapse as shown in Fig. 4. The implementation results were marvelous. One can see on Fig. 5a the solution of the classification problem when ANNs with linear synapses are used. The task is to classify (separate) dots and circles that are distributed on nested circles. Fig 5b represents the solution to the same problem with ANNs with second order synapses.

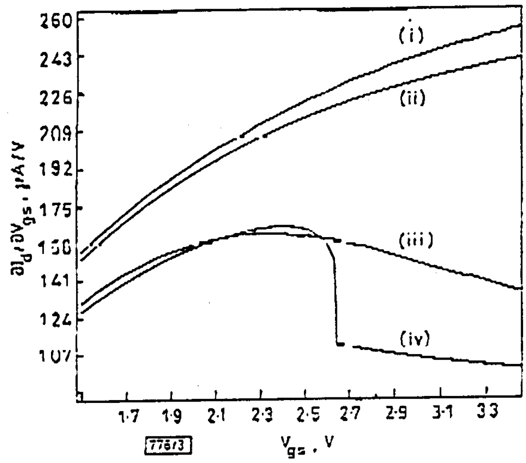


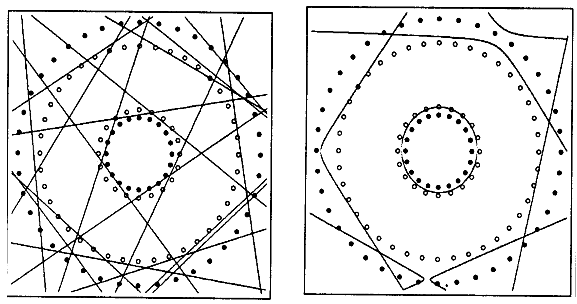
Figure 3. Transconductance of a MOS transistor obtained with SPICE and ANN model

$$f(\mathbf{u}) = \sum_{i=1}^{n} w_i u_i,$$

$$f(\mathbf{u}) = \sum_{i=1}^{n} w_i^{(1)} u_i + \sum_{i=1}^{n} w_i^{(2)} u_i^2 \text{ i}$$

$$f(\mathbf{u}) = \sum_{i=1}^{n} w_i^{(1)} u_i + \sum_{i=1}^{n} w_i^{(2)} u_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} w_{ij}^{(3)} u_i u_j,$$

Figure 4. S. Milenković's introduction of second order synapse



a) b)

Figure 5. Classification with linear (a) and second order (b) synapses

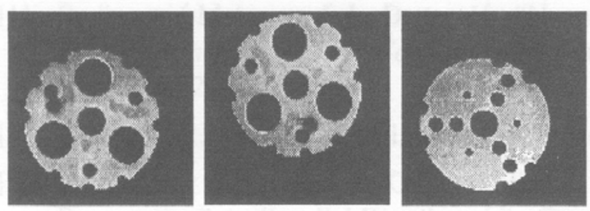


Figure 6. Silicon parts intended to be used in a microelectromechanical system

Based on these results and thanks to the behavioural mixed signal simulator Alecsis developed at LEDA we started international collaboration in the field of microelectromechanical simulation and design with the Technical University of Vienna. As a result a doctorate was granted to S. Rađenović, in Vienna related to implementation of ANNs to automation of the microelectromechanical systems assembly. Parts that were to be classified based on fast comparisons are shown on Fig. 6.

From that moment on, implementation of ANNs was no mystery for LEDA researchers and Ž. Mrčarica, from Vienna, proposed to attack the old problem which we already had solved but in a very complicated manner. It was the dynamics within the magnet with a moving-armature problem. There were two characteristics within the magnet model that were to be captured by ANNs: the magnet's Φ_L-i_L and its F_{mag}-i_L characteristics.

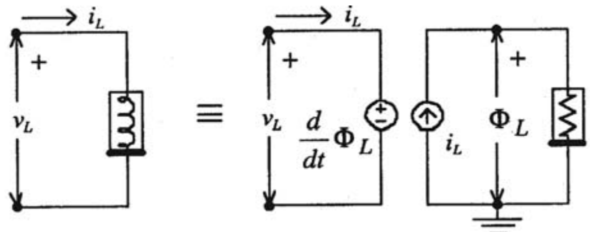


Figure 7. Circuit model of nonlinear inductor

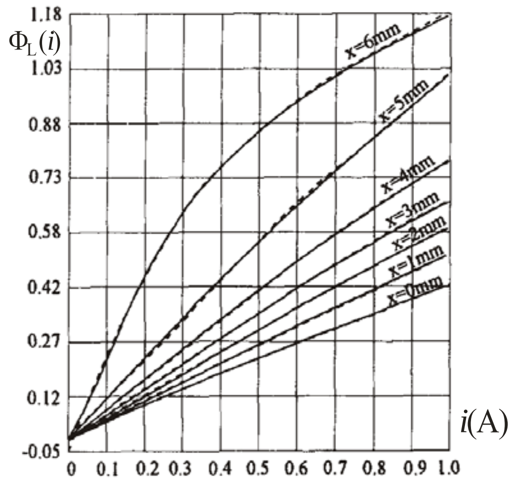


Figure 8. The approximated Φ_L-i_L characteristic of a magnet with moving armature

The task was to get the resistive characteristics and to implement them within the dynamic model of a nonlinear inductor as shown in Fig. 7. After creation of the ANNs (Fig. 8 shows the Φ-i_L , while Fig. 9 depicts the F_{mag}-i_L) simulation was performed and the simulation results, published in SIMPRA, were awarded the Savastano Award by The European Federation of Simulation Societies in 1998.

Similar concept was implemented in the simulation of the Chua's double hook circuit shown in Fig. 10. There is a resistive nonlinearity depicted in Fig.11. To create a model of the Chua's cell that is easily implementable in simulation of complex cellular ANNs, we decided to model only the resistive nonlinearity. The rest of the cell is, of course, easy to model. The modelling results are shown in Fig. 11, while Fig. 12 represents simulation results in a form of chaotic diagram.

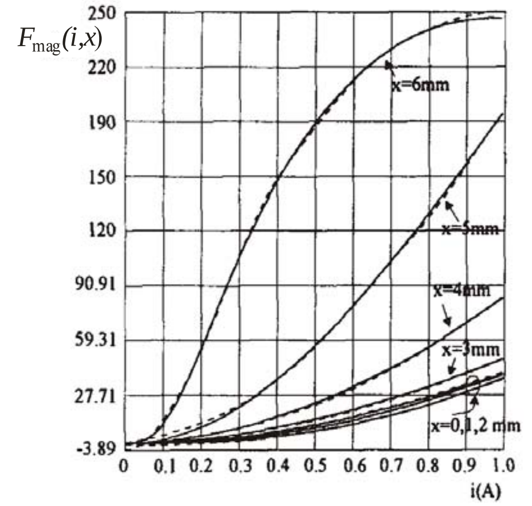


Figure 9. The approximated F_{mag}-i_L characteristic of a magnet with moving armature

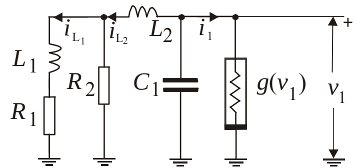


Figure 10. The double hook circuit

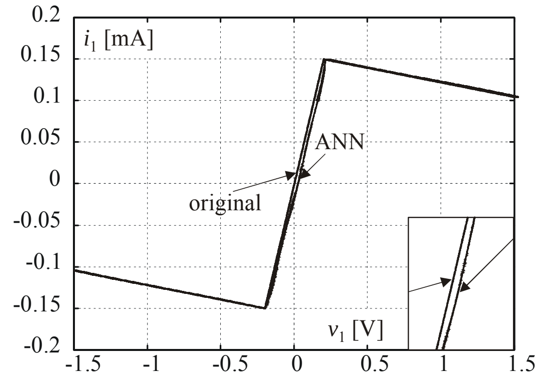


Figure 11. Constitutive relation of the nonlinear conductance and ANN model

The next development was going towards dynamic circuits modelling by a network that models the dynamic behaviour too. Linear circuits were modelled first while culmination of that research came with two results.

The first one is the model of a nonlinear two terminal dynamic network. As a target, the floating mass actuator implemented in hearing-aid systems was chosen. As shown in Fig. 13 it is an iron bar serving as a moving armature of an electromagnet whose axial move is restricted by two rubber balls. The nonlinearity here comes from the saturation of the magnet and from the friction of the balls. The actuator is dynamic not only because of the inductance but also because of the redistribution of the air between chambers during the vibration.

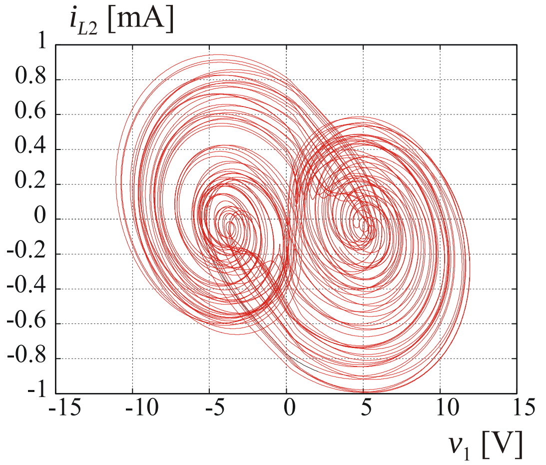


Figure 12. Simulation results for the double hook circuit

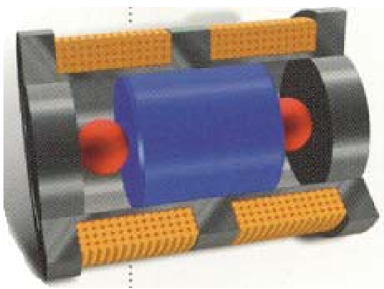


Figure 13. The floating mass actuator

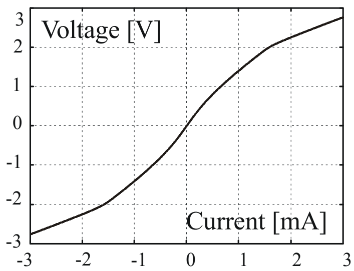


Figure 14. The static characteristic of the NDEC.

Since the proprietor of the IP related to this actuator refused to give us a sample to be measured, starting from its published characteristics we first synthesized an electronic circuit that, in our opinion, mimics the actuator. It was named Nonlinear Dynamic Electronic Circuit i.e. NDEC. The DC *i-v* characteristic of NDEC is shown to be nonlinear in Fig. 14.

To capture the dynamic properties of the actuator we implemented a chirp signal as shown in Fig. 15. It is a frequency modulated signal that is supposed to cover the whole "pass-band" of the frequency characteristic of the actuator.

As opposed to all previous application where feed-forward ANN were used, to model the dynamic behaviour of NDEC recurrent topology of the ANN was to be selected. The structure used is depicted in Fig. 16. It was to be trained with all points of the response depicted in Fig. 17. Note that at least ten points per (any) period were to be generated in order to have complete information for training. The responses of NDEC and the ANN synthesized to model it are shown to overlap in Fig. 18.

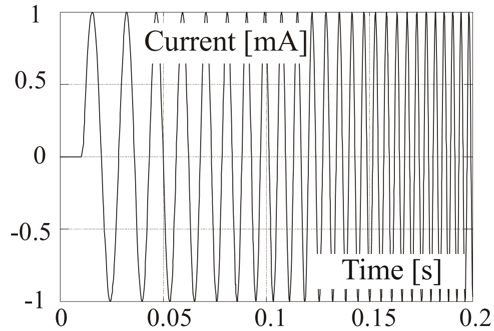


Figure 15. The exciting signal used for modelling.

The model so developed was successfully implemented for simulation of an ensemble consisting of a driving operational amplifier and the floating mass actuator in order to create environment for optimization of the driver's output behaviour for better accommodation to the actuator.

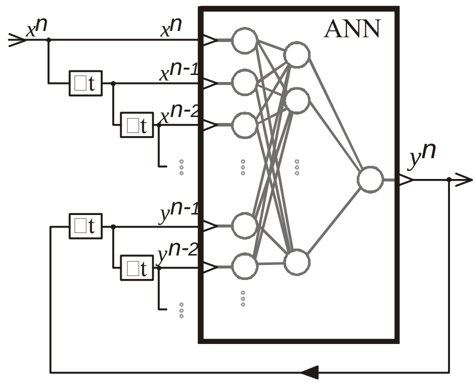


Figure 16. The topology of the proposed ANN.

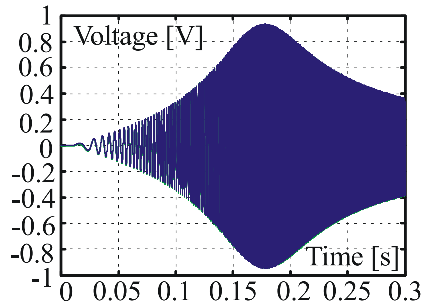


Figure 17. Time domain response of the test NDEC

The second application is related to the simulation of mixed signal circuits where D/A interface may be frequently encountered. The problem is that the analogue load, as depicted in Fig. 19, needs an analogue circuit as a driver.

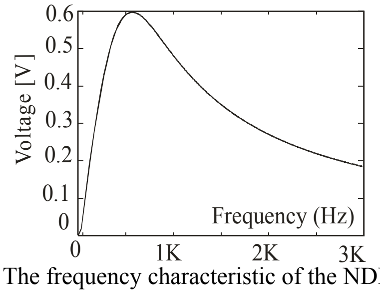


Figure 18. The frequency characteristic of the NDEC and the frequency characteristic of the ANN model overlap

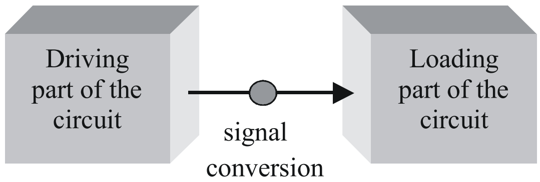


Figure 19. Driver and load interface with conversion of the signal

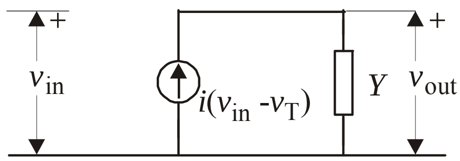


Figure 20. Circuit representation of the model

To create such a driver we needed a circuit model of the output circuitry of the digital part of the D/A interface. In general this solution may be stated as modelling with four terminal dynamic circuits. The circuit of Fig. 20 was proposed.

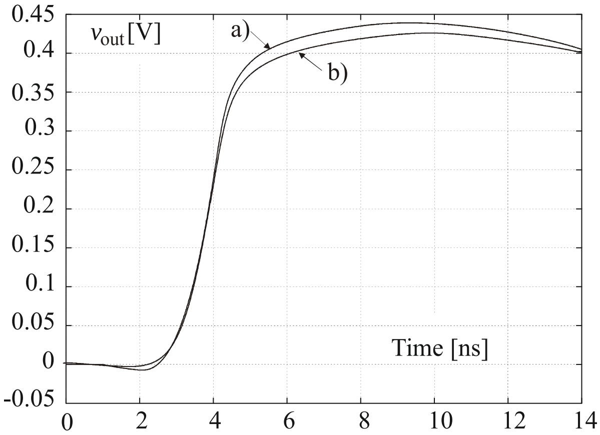


Figure 21. Responses: a) of inverter loaded by a diode and b) of ANN model loaded by a diode

In that circuit the current *i* is controlled by the effective input voltage v_{in}-v_T, and it was chosen to be a tangents hyperbolic function. v_T is a parameter here chosen to be $V_{DD}/2$. On the other side, *Y*, representing the output admittance of the digital part of the interface, was modelled as a two terminal dynamic nonlinear circuit with the ANN of Fig. 17. The modelling and simulation results are best seen in the example where a CMOS inverter (digital), represented by the model of Fig. 20, was loaded with a diode (TTL). From the point of view of loading current that is the most difficult condition for the model. Note, while modelling, unloaded circuit was observed. The simulation results are depicted in Fig. 21. Note the value of the diode voltage which is by far lower than the ordinary value of the CMOS supply voltage being V_{DD}=5 V.

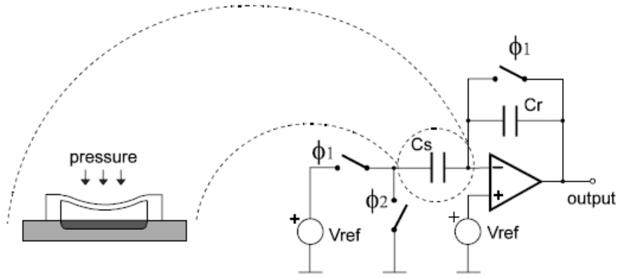


Figure 22. Capacitive pressure sensor and its electronic surroundings

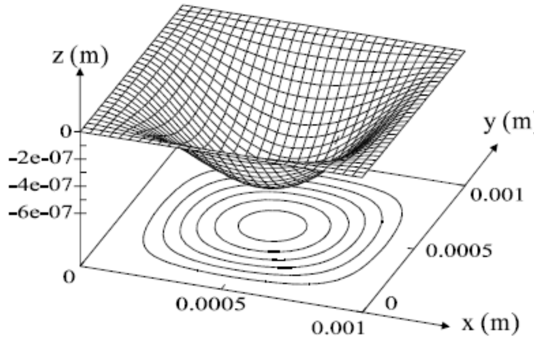


Figure 23. The membrane under pressure. Simulation results.

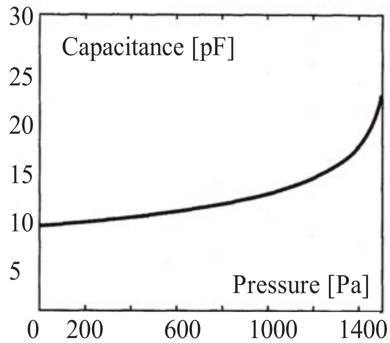


Figure 24. Capacitance versus pressure characteristic

The next development was related to the application of ANN modelling for testing purposes. In fact the ANN was used for acceleration of the verification of the test sequence in MEMS.

Namely, the system of Fig. 22 consists of electronic and mechanical part. While the electronic one is in general defined by ordinary differential equations, the mechanical needs partial differential equations to be described. When solving, the partial equations, after discretization, create a mass of ordinary equations and so, in fact, their solution dominates the simulation time.

On the other side, the number of possible faults in the electronic part of the system is incomparably larger than those in the mechanical. To verify a test sequence targeting the faults in the electronic part one needs repetitive simulation of the whole system. That becomes a serious problem since one has to solve repeatedly the system of partial equations related to the mechanical subsystem.

To avoid that we proposed the mechanical part to be modelled as a lumped element that will reduce the overall number of differential equations to be solved. The procedure was as follows.

By simulation of the mechanical system alone, the dependence of the capacitance on the pressure was extracted as shown in Fig. 24. That is a characteristic of a linear capacitor whose capacitance is controlled by pressure. This curve was approximated by ANN and the model obtained implemented in a mixed signal simulator. In that way instead of solving 995 ordinary equations (the mesh in the mechanical part, as depicted in Fig. 22, was 30 by 33) for every test signal, only a system with 5 ordinary equations was to be solved.

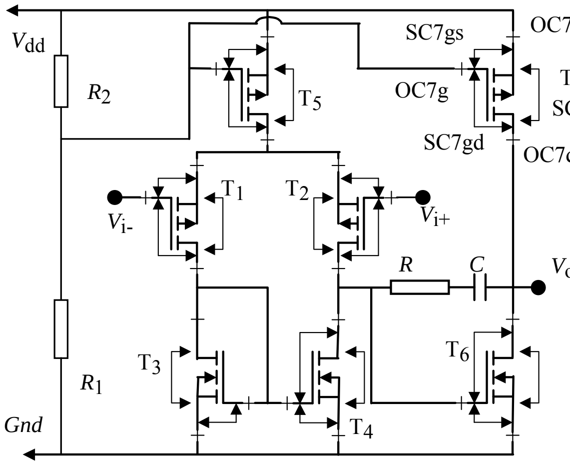


Figure 25. The operational amplifier circuit. SC=short circuit, OC=open circuit

When implementation of ANNs to the problem of diagnosis in analogue circuits is considered, the following was achieved. It was considered, first, that the main responsibility in creating the list of most probable faults in a circuit is on the design engineer. So, the possible fault list and the corresponding fault dictionaries are supposed to be created in design centres in collaboration with foundries. That means no hypotheses are to be created i.e. no faults are to be conceived and searched for, by field engineers when on-site fault effects are observed.

If so, one can memorize the fault dictionary by an ANN and, during exploitation, one may search the ANN in the opposite direction if faulty behaviour of the system is observed. That will lead to a diagnosis. Of course, “opposite direction” means running the ANN with the measured signals at its input what is equivalent to searching the dictionary in order to get the “guilty” fault.

The method was tested on the example of an operational amplifier as depicted in Fig. 25. The so called simulation before test method was applied to create the fault dictionary meaning that faults were inserted in the circuit repetitively and responses were obtained by simulation. Part of the fault dictionary is given in Table 2. In fact, one test point (the output terminal) was selected while three quantities were measured: the DC output voltage (V_O), the DC gain (A), and the 3 dB cut-off frequency ($f_{3\ dB}$). A number (code) was assigned to every fault and was to be learned by the ANN.

TABLE 2
PART OF THE FAULT DICTIONARY FOR THE CIRCUIT OF FIG. 25

Type	A_m	$f_{3\ dB\ m}$ [MHz]	$V_{oDC\ m}$ [V]	Code (m)
FF	419	0.01527	0.127	0
1 L+	0.0053	6.791	0.0497	37
OC1G	0.047	501.187	0.127	49
OC3G	0.049	544.042	0.093	47
SC1DG	0.042	320.440	0.0458	6
SC2DS	0.071	312.071	3.3	27
SC5DS	0.656	0.57	0.0186	55
6 W-	5770	0.0018	0.2146	13
OC5D	0.056	507.298	3.3	25
SC5GS	0.109	0.036	0	2

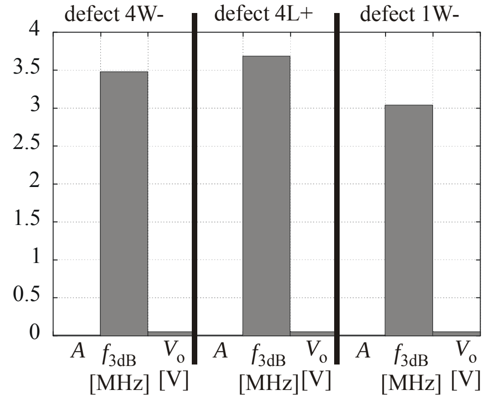


Figure 26. Fault effects of parametric faults 4W- ,4L+ and 1W-

Fig. 26 expresses the difficulties encountered during diagnosis. Namely, fault effects are depicted for three different faults being seen to be very similar. Nevertheless, the ANN developed performed the separation indubitably.

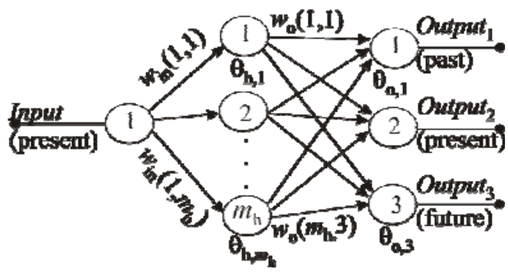


Figure 27. The Feed Forward Accommodated for Prediction (FFAP) structure

The newest efforts in implementation of ANN in electronic design was in prediction. New structure of ANN was proposed named Feed Forward Accommodated for Prediction (FFAP) as depicted in Fig. 27. It learns past present and future values so, by nature, is accommodated for prediction.

This topology was implemented to several problems starting with prediction of quantities of obsolete computers as depicted in Fig. 28 where the period 1991 to 1999 was covered for this quantity in the USA. The y-axis is expressing millions of cubic feet.

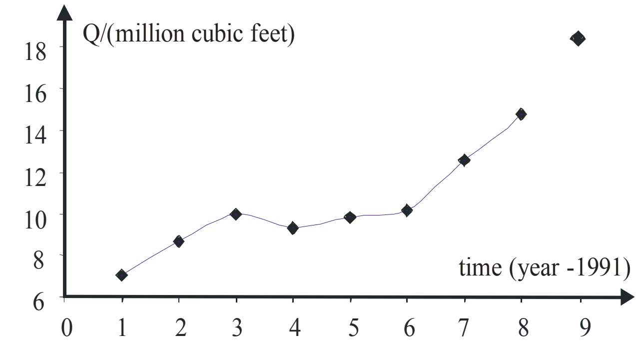


Figure 28. Quantity of obsolete computers

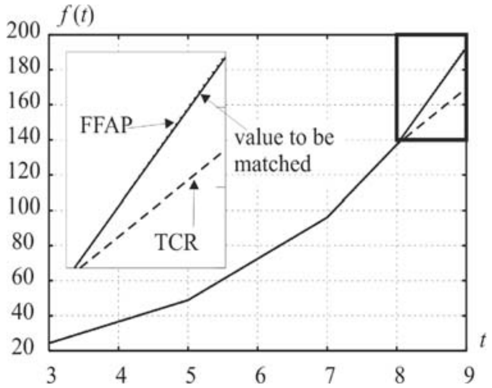


Figure 29. The number of transistor per microprocessor chip in time problem

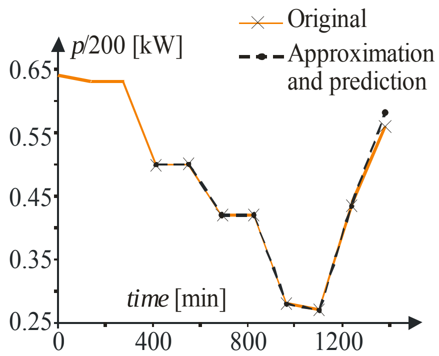


Figure 30. The actual consumption (Solid line), and the approximation (Dashed line) obtained by the EFFAP network.

Using the FFAP structure the value for the 9th year was to be predicted based on the preceding 8. The target value was **18.4** and with a network with ten hidden neurons the value of ***f*(9)= 18.2274** was obtained, the difference, expressed in percentage, being **0.94%**. That we consider an excellent result.

The same method was implemented to the prediction of the number of transistor per microprocessor chip, as a function of time, problem. This was substitution to the application of Moore`s law since it may be used for long term prediction only. The error obtained in this case was only 0.33%.

Finally, the FFAP ANN, with an extension, was applied for short term prediction of electricity load on the suburban level. Fig. 30 depicts the actual and the curve obtained by the FFAP method for two-hour-ahead prediction based on one day long information extended with the consumptions in the same hours of the same days in the previous weeks. The last segment of the dashed line finishes with the prediction. It is a miss of the target value by 3.85%.

III. Conclusion

A historical overview was given of the efforts, ideas, and results of LEDA researchers in implementation of artificial neural networks for pattern recognition, electronic modelling, simulation, testing, diagnosis, and prediction was given.

Acknowledgement

We wish to thank Prof. Đuro Koruga from the University of Belgrade for the fact that he first suggested the research in the field of ANNs to us.

References

General mixed signal electronic simulation and ANN applications

[1] Litovski, V., and Zwolinski, M., ”*VLSI Circuit Simulation And Optimization*”, Chapman and Hall, London, 1997.

[2] Litovski, V., ”*New Methods in Modeling and Simulation of Electronic Circuits and Systems*”, Scientific Review, No. 29-30, 2001-2002, pp.189-207.

[3] Andrejević, M., and Litovski, V., ”*Electronic Modelling Using ANNs For Analogue and Mixed-Mode Behavioural Simulation*”, Proc. of Neurel 2002, Belgrade, Serbia and Montenegro, Sept. 2002, pp. 113-118.

[4] Litovski, V., and Pantić-Tanner, Z., ”*Artificial Neural Network Application In Electronic Circuit Analysis*”, World Congress On Neural Networks, Portland, Oregon, 11-15 July, 1993.

Implementation of ANNs to two- and four- terminal resistive modeling

[5] Litovski, V., Rađenović, J., Mrčarica, Ž., Milenković, S., and Zografski, Z., ”*MOS transistor modelling using neural network*” (in Serbian), Proceedings of the XXXVI Conf. of ETAN, Vol. II, Kopaonik, Yugoslavia, 28.9-1.10, 1992, pp. 19-25.

[6] Glozić, D., Rađenović, J., and Litovski, V., ”*Implementation of MOS transistor modelled by neural*

network in hybrid simulator Alecsis" (in Serbian), Proceedings of XXXVII ETAN Conf., Beograd, Yugoslavia, Sept., 1993.

[7] Litovski, V., Rađenović, J., Mrčarica, Ž., and Milenković, S., "*MOS Transistor Modelling Using Neural Network*", Electronics Letters, Vol. 28, No. 18, August, 1992, pp. 1766-1768.

[8] Andrejević, M., and Litovski, V., "*ANN Application In Modelling of Chua's Circuit*", Proc. of Neurel 2002, Belgrade, Serbia and Montenegro, September 2002, pp. 119-122

[9] Andrejević, M., and Stojilković, S., "*Nonlinear conductance modelling in Josephson junction*" (in Serbian), Proceedings of XLVII Conf. of ETRAN, Herceg Novi, Serbia and Montenegro, Jun 2003, pp. I72-I75.

Implementation of ANNs to two- and four- terminal dynamic modeling

[10] Zarković, K., Ilić, T., Savić, M., and Litovski, V., "*ANN application in Modeling of Dynamic Two-Terminal Linear Circuits*", Proceedings of ETAI'2000, September 2000, Ohrid, Macedonia, pp. E-27-E-30.

[11] Ilić, T., Zarković, K., Litovski, V., and Damper, R., "*ANN Application in Modelling of Dynamic Linear Circuits*", Proceedings of The Small Systems Simulation Symposium, SSSS2000, Niš, Yugoslavia, Sept. 2000, pp. 43-47.

[12] Andrejević, M., and Litovski, V., "*ANN Application to modelling of reactive nonlinear two-port circuits*" (in Serbian), Tehnika (Elektrotehnika), Vol. 51, No. 4-5, May 2002, pp. E1-E11.

[13] Andrejević, M., and Litovski, V., "*Non-Linear Dynamic Network Modelling Using Neural Networks*", Int. Congress on Computational and Applied Mathematics, Leuven, Belgium, 22. July-26. July, 2002, pp. 16.

[14] Litovski, V., Mrčarica, Ž., and Ilić, T., "*Simulation of Non-Linear Magnetic Circuits Modelled Using Artificial Neural Network*", Journal Simulation Practice and Theory, Vol. 5, 1997, pp. 553-570.

[15] Litovski, V., and Andrejević Stošović, M., "*Nonlinear modelling in biomedical applications using ANNs*", Proc. of the International Conference on Biomedical Electronics and Devices, Biodevices 2008, 28. - 31. January 2008., Funchal, Madeira, Portugal, Vol. 1, pp.115-116.

[16] Andrejević, M., and Litovski, V., "*Electronic Modelling Using ANNs For Analogue and Mixed-Mode Behavioural Simulation*", Journal of Automatic Control, University of Belgrade, Serbia and Montenegro, Vol. 13, No. 1, 2003, pp. 31-37.

[17] Litovski, V., Andrejević, M., "*ANN Application in Modelling of A/D Interfaces for Mixed-Mode Behavioral Simulation*", Proc. of the XLVI Conf. of ETRAN, ETRAN 2002, June 2002, Banja Vrućica, Bosnia and Herzegovina, pp. I.51-I.54.

[18] Litovski V., Andrejević M., and Damper. R., "*Modeling the D/A interface for mixed-mode behavioral simulation*", EUROCON 2003, Ljubljana, Slovenia, Sept. 2003, pp. A130-A133.

[19] Litovski, V., Andrejević, M., Petković, P., and Damper, R., "*ANN Application to Modelling of the D/A and A/D Interface for Mixed-Mode Behavioural Simulation*", Journal of Circuits, Systems and Computers, Vol. 13, No. 1, February 2004, pp. 181-192.

Use of ANNs for test pattern evaluation of electronic systems

[20] Andrejević, M., Litovski, V., and Zwolinski, M., "*Black-Box Application in Modeling of Micro-electro-mechanical Systems*", Electronics, Vol. 8, No. 2, December 2004, pp. 27-30.

[21] Litovski, V., Andrejević, M., and Zwolinski, M., "*Acceleration of MEMS fault simulation using ANNs*", Electronics, Vol. 8, No. 2, December 2004, pp. 49-53.

[22] Litovski V., Andrejević, M., and Zwolinski M., "*Behavioural Modelling, Simulation, Test and Diagnosis of MEMS using ANNs*", 2005 IEEE International Symposium on Circuits and Systems, Kobe, Japan, 2005, pp. 5182-5185.

Diagnosis of mixed signal systems based on ANN implementation

[23] Litovski, V., and Andrejević, M., "*ANN application in electronic circuits diagnosis*", Proc. of the XLVIII ETRAN Conference, Čačak, Serbia and Montenegro, June 6-10, 2004, Vol. 1, pp. 21-24.

[24] Andrejević, M., and Litovski, V., "*ANN application in electronic diagnosis - Preliminary results*", Proc. of MIEL 2004, Niš, Serbia and Montenegro, 2004, Vol. 2, pp. 597-600.

[25] Litovski, V., Andrejević, M., and Zwolinski, M., "*ANN based modeling, testing, and diagnosis of MEMS*", Proc. of the 7th Seminar on Neural network Applications in Electronic engineering, NEUREL 2004, Sept. 2004, Belgrade, Serbia and Montenegro, pp. 183-188.

[26] Litovski, V., Andrejević, M., and Zwolinski, M., "*Analog electronic circuit diagnosis based on ANNs* ", Microelectronics Reliability, Vol. 46 (2006), pp. 1382-1391.

[27] Andrejević, M., Petrović, V., Mirković, D., and Litovski, V. B., "*Delay defects diagnosis using ANNs*", Proc. Of the L Conference of ETRAN, Belgrade, Serbia, June 2006, pp. EL, 1, 27-30.

[28] Andrejević, M., and Litovski, V., "*Fault diagnosis in analog part of mixed-mode circuits*", Proc. of the 6th Symposium on Industrial Electronics, INDEL 2006, Banja Luka, Bosnia and Herzegovina, November 2006, pp. 117-120.

[29] Andrejević, M., Litovski, V., and Zwolinski, M., "*Fault Diagnosis in Digital Part of Mixed-Mode Circuits*", Proc. of the 25th Int. Conf. On Microelectronics (MIEL2006),

Belgrade, Serbia and Montenegro, 14-17 May, 2006, pp. 437-440.

[30] Andrejević, M., and Litovski, V., "*Fault diagnosis in digital part of sigma-delta converter*", Proceedings of the 8th Seminar on Neural network application in electrical engineering, NEUREL '2006, Belgrade, Serbia and Montenegro, pp. 177-180.

[31] Andrejević Stošović, M., and Litovski V., "*Hierarchical Approach to Diagnosis using ANNs*", Proc. of IEEE 25th International Conference on Microelectronics (MIEL2008), Niš, Serbia, May 2008, Vol. 2 pp. 395-398

Prediction

[32] Milojković, J, and Litovski, V.B., „*Dynamic Short-Term Forecasting Of Electricity Load Using Feed-Forward ANNs*", International Journal of Engineering Intelligent Systems for Electrical Engineering and Telecommunication, ISSN 1472-8915, accepted.

[33] Milojković, J. and Litovski, V., "*Comparison of Some ANN Based Forecasting Methods Implemented on Short Time Series*", 9th Symposium on Neural Network Applications in Electrical Engineering, NEUREL-2008, Belgrade, 2008, pp. 179-179.

[34] Milojković, J., and Litovski, V.B., "*Prediction in Electronics based on limited information*", Proceedings of the 8th WSEAS Int. Conf. on Electronics, Hardware, wireless and optical communications, EHAC'09, Cambridge, UK, February 2009, pp. 33-38.

[35] Milojković, J., and Litovski, V.B., "*Short-Term Forecasting Of The Electricity Load At Suburban Level*", IX National Conference with International Participation, ETAI 2009, Ohrid, Macedonia, Septembar 2009, prihvaćeno za objavljivanje.

[36] Milojković, J., Litovski, V., "*Short-Term Forecasting Of Electricity Load Using Recurrent Anns*", 15th International Symposium on Power Electronics – Ee2009, Novi Sad, Serbia, October, 2009. Paper No. T1-1.7, pp. 1-5.

[37] Milojković, B., i Litovski, V. B., «New methods of prediction for sustainable development applications », Proc. of the LI Conf. Of ETRAN, Herceg Novi, June, 2007, paper No. EL1.8. (in Serbian)

[38] Milojković, J. i Litovski, V.B., „Methods of prediction for ecological needs", Proc. of Ekoist'08, Ecological trouth, June 2008, Soko Banja, pp. 543-548.

[39] Milojković, J., Litovski, V., "*One step ahead prediction in electronics based on limited information*", Proc. of the LIII Conf. of ETRAN, June 2009, Vrnjačka Banja, pp. EL 1.7-1-4.

Miscellaneous

[40] Rađenović-Mrčarica, J., Mrčarica, Ž., Detter, H., and Litovski, V., "*Neural Network Visual Recognition For Automation Of The Microelectromechanical Systems Assembly*", International Journal on Neural Systems, Vol. 8, No. 1, Feb., 1997, pp. 69-79.

[41] Rađenović-Mrčarica, J., Mrčarica, Ž., Litovski, V., and Detter, H., "*Application Of Neural Networks In Microsystem Assembly*", 4th Seminar on Neural Network Applications in Electrical Engineering, NEUREL '97, Belgrade, Sept., 1997, pp. 157-160.

[42] Rađenović-Mrčarica, J., Mrčarica, Ž., Detter, H., Brenner, W., and Litovski, V., "*Neural Network Visual Recognition Applied To Microelectromechanical Parts Assembly*", Int. Conf. on Engineering Applications of Neural Networks, EANN '96, Kingston upon Thames, 1996, pp. 325-328.

[43] Ranđelović, Z., and Litovski, V., "*An Application Of Hopfield-Tank's Neural Net On Channel Routing*", 15-16 International Annual School on Semiconductor and Hybrid Technologies, 1992-93, Sozopol, Bulgaria, May, 1994, pp. 106-111.

[44] Milenković, S., Litovski, V., and Obradović, Z., "*Nondeterminism in Artificial Neural Networks*", International Memorial Conference D. S. Mitrinović, Niš, Yugoslavia, 20-22 Jun, 1996.

[45] Milenković, S., Obradović, Z., and Litovski, V., "*Anneaing Based Dynamic Learning in Second-Order Neural Networks*", International Conference on Neural Networks, ICNN '96, Washington, D.C., USA, 3.-6. June, 1996, pp. 458-463.

[46] Zarković, K., Litovski, V., and Stojilković, S., "*Acceleration of artificial neural networks learning using statistical methods*" (in Serbian), Proc. of the XXXVIII Conf. Of ETRAN, Vol. III, Niš, Yugoslavia, June 1994, pp. 205-206.

[47] Milenković, S., Risojević, V., and Litovski, V., "*Noise Based Gradient Descent Learning*", Proc. of 4th Seminar on Neural Networks Appl. in Electrical Engineering, NEUREL '97, Belgrade, Sept., 1997, pp. 28-33.

[48] Milenković, S., Obradović, Z., and Litovski, V., "*Dynamic learning of second-order neural networks based on simulated annealing*" (in Serbian), 3rd Seminar on Neural Network Applications in Electrotechnics NEUREL-95, Belgrade, Sept., 1995.