NONLINEAR MODELLING IN BIOMEDICAL APPLICATIONS USING ANNS

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Abstract: During the design of many biomedical prostheses based on electrical and electronic fundamental actions, simulation is indispensable. It comprises, however, necessity for adequate models to be used. Main difficulties related to the modelling of such devices is their nonlinearity and dynamic behavior. Here we report application of recurrent artificial neural network for modelling of a nonlinear two-terminal circuit equivalent to a specific implantable hearing device. The method is general in the sense that any nonlinear dynamic two-terminal device or circuit may be modelled in the same way. The model generated was successfully used for simulation and optimization of a driver (operational amplifier) - transducer ensemble. That confirms our claim that optimization in the electrical domain should take place in order to achieve best performance of the hearing aid. It is to be contrasted to the optical methods based on surgery frequently used.

1 INTRODUCTION

Most of the prostheses that are used nowadays are based on electrical and/or electronic transducers performing appropriate conversion of electrical signals into movement or vice-versa. Among these are the implantable hearing aids (IHA) that are mounted in the middle ear (Hakansson, 1994) so bypassing the tympanic membrane. As for example that will demonstrate the concepts we intend to implement, Fig. 1a represents a cross section of a part of the ear and the way how the IHA is mounted. This structure is known as floating mass transducer (FMT) (Dietz, T.G., 1997), (Ball G., 1996), (Dazert, S., 2000) as depicted in Fig. 1b. It consists of a solenoid (coil) that produces magnetic field forcing the iron core to move forth-and-back. The movement is limited by rubber balls that become compressed and produce repulsive force to limit the amplitude of the displacement. Note that the chamber is in vacuum to avoid acoustic effects due to air compression and decompression that would arise at the ends of the core. As an alternative to the FMT one may find TICA (totally integrated cochlear amplifier) as described in (Heinrich, B. M., 2005). The proceedings that follow are not restricted to any specific IHA.

The system may be characterized as two-terminal, electro-magneto-mechanical, dynamic, and nonlinear. The dynamic behaviour comes mainly from the coil while much of the nonlinearity comes from the balls (or springs) that are distorted under the pressure force. One can see from Fig. 1a that this device is excited by an electronic circuit - driver - that we here consider is an operational amplifier (OA) situated at the output of the complex electronic system that controls the intensity and the frequency characteristic of the signal coming from the microphone.

When designing such a system we may accept two approaches. One is to consider the electronic circuit as fixed and to optimize the FMT to get the desired performance. In the opposite approach, that will be considered here, we suppose that the FMT has fixed characteristics while the driver is subject to optimization.

To perform this we need electrical model, i.e. voltage-current dependence, of the FMT that will be used in conjunction with the transistor model existing in usual electronic simulator. That will allow for repetitive simulations with output-transistor's features optimized until optimum is reached.

In this paper we propose a new modelling procedure that results in a closed form model of nonlinear dynamic two port devices suitable for simulation application. It is based on implementation of so called recurrent artificial neural networks (ANN). We will also present the results obtained after one step

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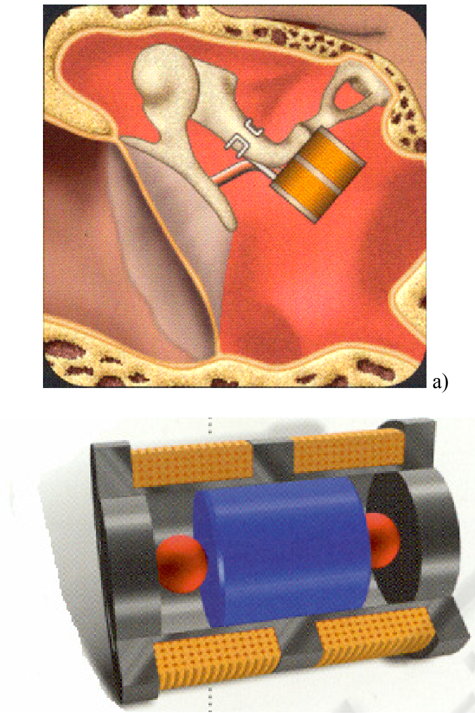
of driver optimization that represent a serious improvement in the system's high-frequency characteristic.

The paper is organized in the following way. We first discuss the problem of electronic modelling. After that we introduce the ANN for implementation of the black-box modelling concept. Follows the implementation and the results obtained.



a)

b)

Figure 1: a) Cross section of the ear showing the implant mounted on the incus, and b) the inner structure of the implant. (Photographs taken from Symphonix Devices marketing material).

2 ELECTRONIC DEVICE MODELLING

As mentioned above, we are looking for the current-voltage characteristic of the device under consideration expressed by a set of mathematical expressions. The following difficulties are encountered when generating a model of nonlinear dynamic devices:

- choice of approximation function
- choice of the excitation signal

To achieve this, two approaches are implemented (Chua, L., 1975).

a. Physical approach

To implement this approach one needs to understand physical processes in the component or system. Advantages of this approach are: the procedure is understandable, and there exists the correspondence between the physical and technological quantities and model parameters.

There are no disadvantages of the physical approach, but there is a problem when we do not understand the whole physics of the component, or when we are not aware of all the effects influencing the component including parasitics.

b. *Black box approach*

When using this concept, the characteristics of the modelling object have to be **measured** first, and then approximated using functions that fulfill the requirements imposed by the method for equation formulation implemented within the simulator.

Advantage of the black-box approach is getting a perfect model obtained with no need to fully know and understand the mechanisms behind the component's operation. This method is specially convenient for sensors and actuators modelling, because the price of modelling is very low.

Disadvantages related to this approach are:

- Difficult choice of approximation function (which function is the most convenient?)
- The model application is limited only to the conditions under which the measurement was done, referring to the signals (amplitudes, frequencies, wave forms) and ambient (temperature, brightness and so on).
- A special problem is the choice of the test signals needed for establishing the device properties by measurements.
- There is no correspondence between physical and technological process parameters and model parameters.

Having in mind that the ambient and signal conditions for operation of the transducer under consideration are well established, in order to apply this method, we will need to find appropriate approximants. That will be ANNs.

3 ANNS AND NETWORK MODELLING

Artificial neural network is (Hecht-Nielsen, R., 1989.):

- A set of mutually coupled computational operators with specific topology and computational potential, and
- algorithm for determining the operator coefficients (i.e. learning).

ANNs are considered to be universal approximators, meaning that ANN can interpolate any function

(Scarselli, F., 1998). It is the motive for using ANNs in modelling in black-box approach. They solve one of the basic problems: choice of approximation function. To shorten the explanations we refer to (Hecht-Nielsen, R., 1989) for detailed explanation of the ANN's structure and the properties of the processing elements.

Feed-forward ANNs were successfully used for many modelling applications the first being the modelling of the MOS transistor (Litovski, V., 1992). In (Litovski, V., 1997) a magnet with moving armature was modelled for the first time by ANNs. That, however, having no memory properties, is not convenient for modelling of dynamic circuits and systems. In order to introduce the memory property a structure depicted in Fig. 2 has to be used. It is time a delayed recurrent ANN.

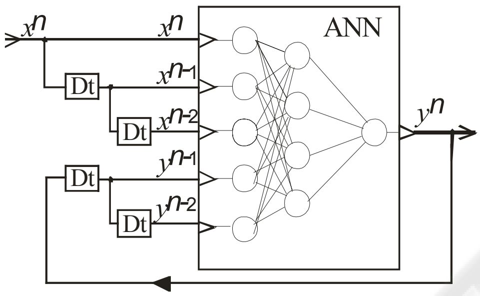


Figure 2: A time delayed recurrent ANN.

The learning procedures for such a network including choice of its complexity may be found in (Bernieri, A., 1994.).

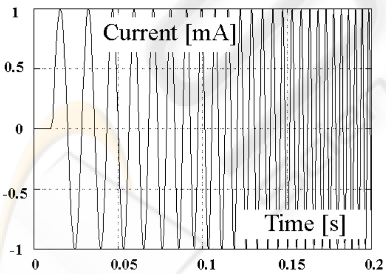


Figure 3: The exciting signal used for modelling.

To capture the dynamic properties of the system to be modelled and its nonlinearities by measurement, we propose the chirp signal depicted in Fig. 3. It is a constant amplitude linearly frequency modulated signal. The frequency interval is to be chosen so that to cover the complete frequency characteristic of the device while the amplitude is supposed to be large enough to capture all relevant nonlinearities.

To create the neural model of the device under consideration, after measurement, samples from the time domain response of the devices are used to train the ANN, as described in (Andrejević, M., 2002) and (Andrejević, M., 2003). After training the ANN is supposed to capture all electrical properties of the device seen from its terminals.

4 IMPLEMENTATION EXAMPLE

In order to demonstrate the method, instead of using a specific device, we propose a nonlinear dynamic electronic circuit (NDEC) as depicted in Fig. 4.

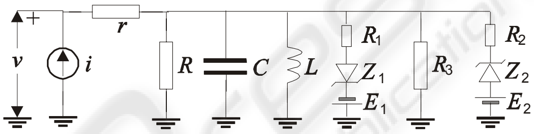


Figure 4: Nonlinear dynamic two terminal circuit.

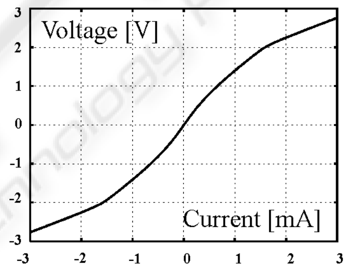


Figure 5: The static characteristic of the NDEC.

Its static characteristic is depicted in Fig. 5, while Fig. 6 represents its response to a chirp signal. After extracting the envelope one obtains the frequency response of the circuit as depicted in Fig. 7.

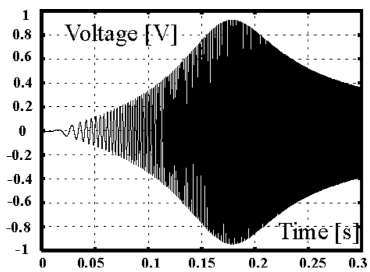


Figure 6: Time domain response of the test circuit.

Samples of the response from Fig. 6 were used to train the ANN in the time domain. Its response after training is exactly the same as the response of the original NDEC and is drawn in Fig. 7 overlapped with the frequency response of the original circuit.

That was used to load an OA supposed to drive the NDEC. The overall response of the driver-transducer ensemble is depicted in Fig. 8. This result is by itself an important one because it shows the ability of simulation of the NDEC in every environment.

To go further we redesigned (only one iteration) the output part of the OA in order to improve the frequency response of the ensemble. The result of the new design is depicted in Fig. 9. representing a full success.

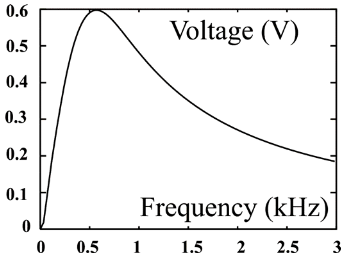


Figure 7: Frequency characteristic of the element being modelled (envelope of the time response), and Frequency characteristic of the model.

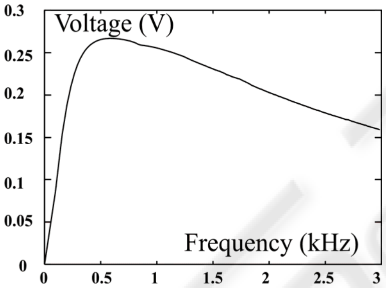


Figure 8: Frequency characteristic of the response of the OA loaded by the NDEC.

5 CONCLUSIONS

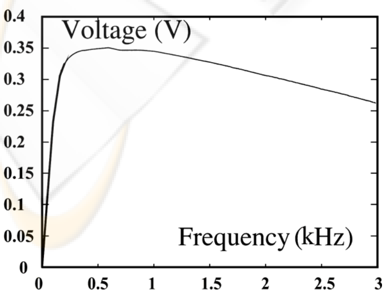


Figure 9: Frequency characteristic of the improved OA loaded by the NDEC.

A procedure for modelling nonlinear dynamic two-terminal circuits equivalent to IHAs is described. It enables complete characterization of the device and, in the same time, simulation and optimization of the driving circuitry. That, we consider, is more effective way for characterization of the device in comparison with optical methods, not to mention the optimization possibilities.

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