Microelectronic Differential Amplifier Functionally Analogous to Hydrogen Bonding Network

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Abstract - **A microelectronic circuit functionally analogous to hydrogen bonding network is developed and analyzed. The simulations, carried out in Matlab, demonstrate that the Matlab biocircuit emulates the behavior of the conventional electrical circuit of a differential amplifier. The real microelectronic circuit with output characteristics that are similar to the output characteristics of the hydrogen bonding network is implemented in CADENCE. The CADANCE circuit shows very good agreement with its Matlab counterpart.**

Keywords – **Hydrogen bonding network, microelectronic circuits, biocircuits, proton transfer.**

I. INTRODUCTION

Recently, the development of algorithms and devices taken from the nature is of great interest for microelectronics. For example, the artificial neuron networks operate as nature objects [1, 2]. The implemented genetic algorithm in them is appropriate for processing deferent nonlinear functions.

On the other hand, the proteins and their hydrogen bonding networks can also have functions applicable to microelectronics. Suitable object for microelectronics application is the proton transfer protein Bacteriorhodopsin (bR). It transfers the protons by its own hydrogen bonding network. Its characteristic [3] of proton current versus voltage is similar to the output characteristic of the microelectronic circuit of a differential amplifier.

Signal transfer (proton transfer) in other hydrogen bonding network is also studied for microelectronic purposes [4]. The network shown in Figure 1 is extracted from β-lactamase and it includes atoms from the protein and water molecules. The model of proton transfer in hydrogen bonds is developed based on Marcus theory and the protein electrostatic theory [5].

The block-elements that emulate the operation of hydrogen bonds are modeled in Matlab and static and then dynamic analyses of the circuits are performed in Matlab [6]. The Matlab code is easily converted into SPICE code that is generally used in CAD design systems.

The simulation shows that the hydrogen bonding network operates similarly to a differential amplifier. Next, the conventional microelectronic circuit of a differential amplifier is created in CADANCE [7] to emulate the characteristics of the hydrogen bonding network.

II. CIRCUIT ANALYSIS

The hydrogen bonding network with water molecules and the microelectronic circuit have equal output characteristics. The hydrogen bonding network is shown on Figure 1. Figure 2 shows the microelectronic circuit with block-elements that emulate the network of Figure 1. In Figure 3 is given the microelectronic circuit that is functionally analogous to the hydrogen bonding network. In this case the microelectronic circuit is a simple classic differential amplifier with two inputs and two outputs.

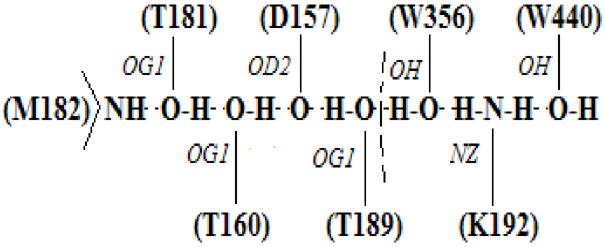

FIGURE 1. HYDROGEN BONDING NETWORK, (M182) IS METHIONINE RESIDUE, OG1 IS HYDROXYL OXYGEN OF THREONINE RESIDUES (T160,181,189), OD2 IS CARBOXYL OXYGEN OF ASPARTIC ACID RESIDUE (D157).

The hydrogen bonding network and its properties are taken from [8]. The branches of the circuit are formed by the Methionine residues M182, Lysine acid K192, Aspartate residues D157 and the water molecules of TEM1 β-lactamase protein. The bonds between the protein residues are formed by water molecules actively participating in the information transfer through the network. M182N and K192NZ are assumed to represent current sources because they are strong proton donors. D157OD2 is strong proton acceptor and it can be considered as output element that sums two signals. The other residues are represented by three-terminal block-

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elements each of them having equal input and output voltages and different currents.

The proton current in the hydrogen bonds depends on the value of pH. Changing the pH causes polarization and ionization of the protein groups. In result, the charges in protein-water system are redistributed and the donor/ acceptor electrostatic potentials change. The proton transfer parameter (respectively proton current) between changes as well.

Figure 2 shows the hydrogen bonds modeled as three- and four-terminal block-elements. The I-V characteristics of the block-elements are proportional to the K-V characteristics of the respective hydrogen bonds investigated in [8]. The current (I) of each block-element represents the proton transfer parameter (K) of each hydrogen bond and the voltage (V) of each block-element represents the electrostatic potential (El. pot.).

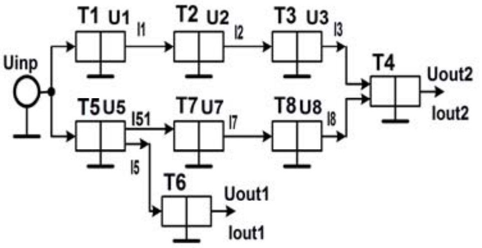

FIGURE 2. MICROELECTRONIC CIRCUIT THAT EMULATES THE NETWORK IN FIGURE1.

Figure 3 shows the real microelectronic circuit of a differential amplifier. For simulate the circuit is used scheme editor CADENCE Design Framework II. He is general interface from programmer product to simulate the integrated circuits in CADENCE. In this case a standard AMS 0.35µm CMOS technology is used. The transistors in Figure 3 have the following design parameters: width 10 µm, length 0.6 µm.

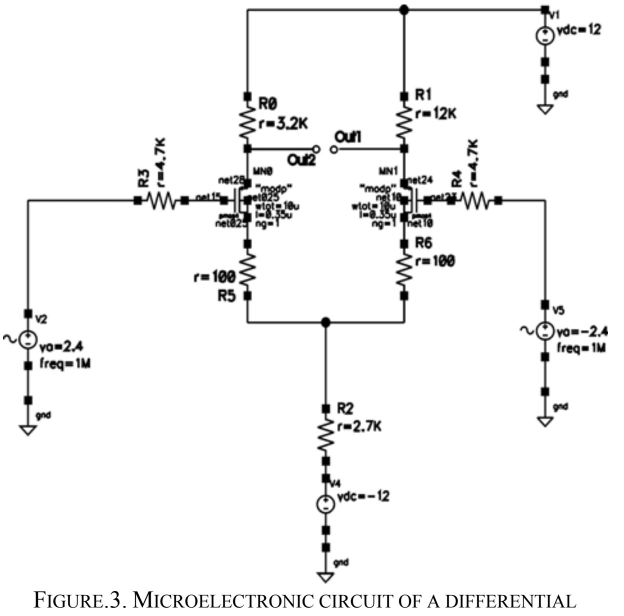

FIGURE.3. MICROELECTRONIC CIRCUIT OF A DIFFERENTIAL AMPLIFIER FUNCTIONALLY ANALOGOUS TO THE HYDROGEN BONDING NETWORK.

The circuit has two inputs and two outputs. At both inputs are applied equal voltage levels. The amplifier outputs are asymmetric to obtain different current on outputs, similar to characteristics obtained from simulation of Figure 3. These asymmetric outputs are due to the difference in resistances: R0 = 3.2 [kΩ] and R1 = 12 [kΩ].

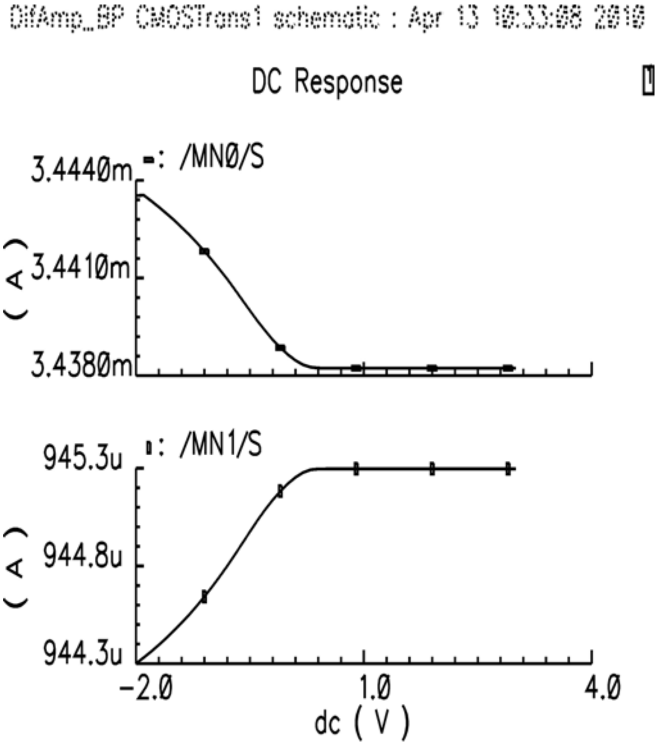

FIGURE 4. OUTPUT CHARACTERISTICS OF THE CADANCE CIRCUIT SIMULATING DIFFERENTIAL AMPLIFIER.

III. STATIC ANALYSIS

The static analysis is performed by feeding input voltage between -2 and +3 [V]. Figure 4 shows the output currents of the differential amplifier simulated in Cadence. Figure 5 and Figure 6 depict the currents of the Matlab simulation of the hydrogen bonding network (output characteristics).

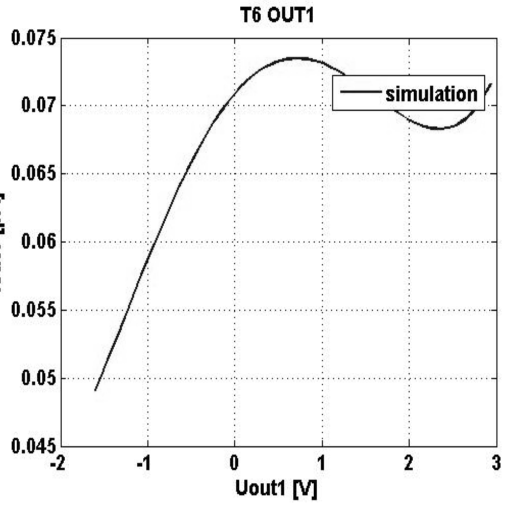

FIGURE 5. FIRST OUTPUT CHARACTERISTIC OF THE MATLAB CIRCUIT SIMULATING THE HYDROGEN BONDING NETWORK.

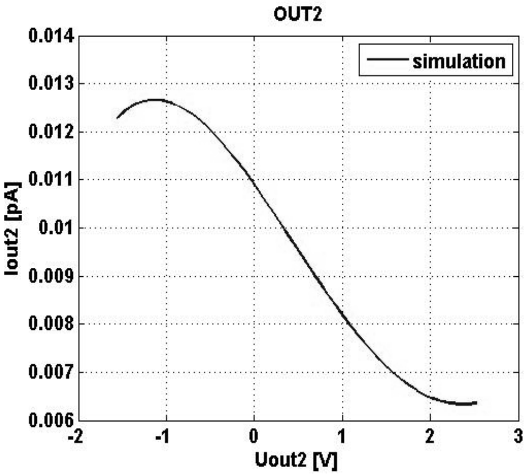

FIGURE 6. SECOND OUTPUT CHARACTERISTICS OF THE MATLAB CIRCUIT SIMULATING THE HYDROGEN BONDING NETWORK.

The shape of the curves obtained by simulations of differential amplifier and block-elements are shown in Figure 4, Figure 5 and Figure 6. As it can be seen they are similar. The shift between the first current with respect to the second current remains unchanged (the first current is almost three times larger than the second current). The voltage levels in both simulations are comparable, but the current levels are different. In the simulations of the Matlab circuit the currents are in the pA-range while in the simulations of the CADANCE circuit the output currents are in the mA-range. This is the main difference of the simulations.

IV. DYNAMIC ANALYSIS

The dynamic analysis is conducted by feeding input voltage between -2.4 and 2.4 [V] at frequency of 1 [MHz] (Figure 7). The applied input voltage is same for both circuits.

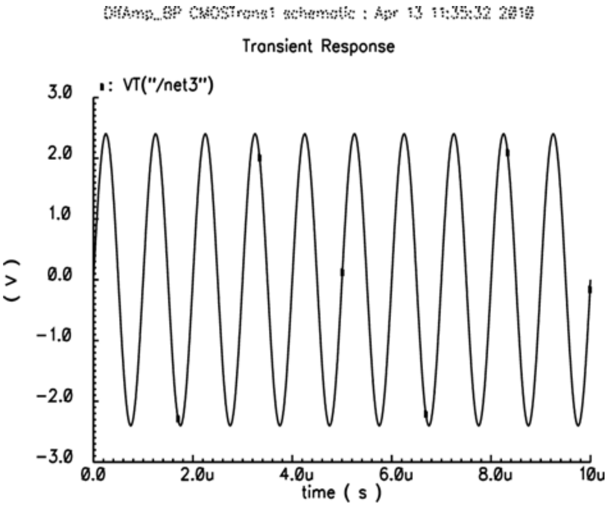

FIGURE 7. INPUT VOLTAGE VERSUS TIME.

The results of analysis of the CADANCE circuit (Figure 8) show that the output currents are similar in shape and with positive amplitudes. They are similar to the characteristics of the Matlab circuit. The current amplitude from Cadence circuit characteristics are in three orders bigger than current amplitude of Matlab circuit characteristics (Figure 9).

The outputs of the two simulated circuits differ in amplitude and frequency. This difference originates by the fact that the differential amplifier is simulated in the design kit of the state-of-the-art AMS 0.35 µm CMOS technology in Cadence while the block-element circuit is simulated in Matlab in the ideal case without accounting for any unwanted effects.

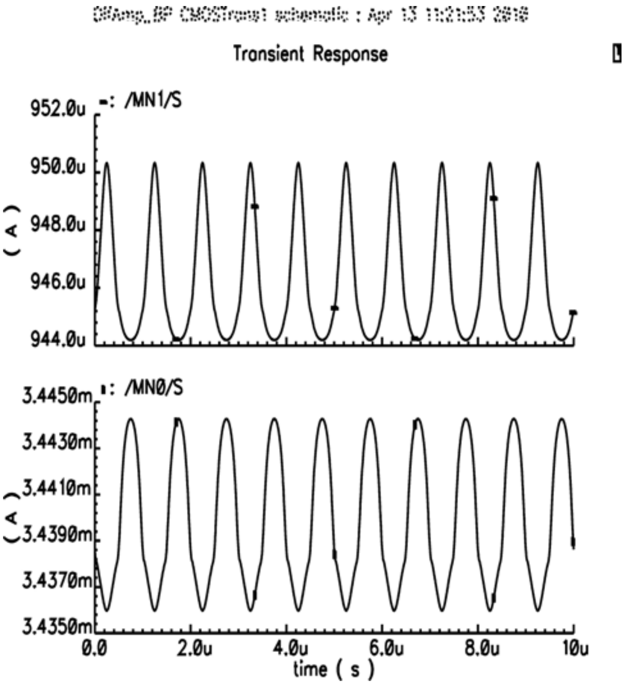

FIGURE 8. INPUT CURRENT OF THE DIFFERENTIAL AMPLIFIER VERSUS TIME.

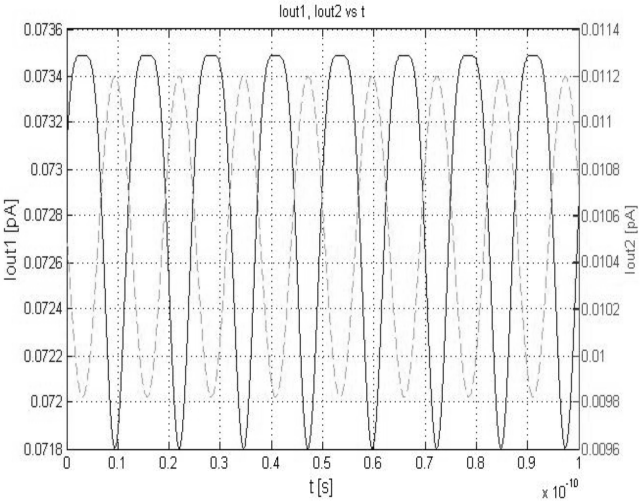

FIGURE 9. OUTPUT CURRENTS OF THE CIRCUIT REALIZED BY BLOCK-ELEMENTS VERSUS TIME.

In the Matlab circuit the frequency of the current is on the order of 10 GHz and in the Cadence circuit it is 1 MHz. The lower frequency in Cadence circuit is due to the CMOS technology used. The simulations at 10 MHz in Cadence give results that increasingly deviate from the Matlab curves.

V. CONCLUSION

We demonstrated that the operation of the hydrogen bonding network might be represented by conventional microelectronic circuits. The simulation of the microelectronic differential amplifier in CADENCE well emulates the behavior of the hydrogen bonding network simulated in Matlab. This proves that the algorithm of operation of the hydrogen bonding networks can be applied to microelectronics by designing state-of-the-art circuits.

VI. ACKNOWLEDGEMENT

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