

PATIENT SIMULATOR APPLIED TO AUDITORY EVOKED POTENTIALS, ELECTROCARDIOGRAPHY AND ELECTRONYSTAGMOGRAPHY

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Abstract: This paper describes an electronic device, named SimPac I, developed to simulate auditory evoked potentials of short, middle and long latencies, ECG and electronystagmography signals. It uses sampled waveforms in order to better reproduce real physiologic AEPs. The simulator is based on the ADuC841 microconverter, a device with an 8052-like core, FLASH memory and two 12-bit DACs. SimPac I is portable and easy to operate, and it is very useful for calibration of AEP, ECG, ENG and VENG systems during manufacture and maintenance. The simulator can also be used to support development and testing of DSP algorithms intended to filter and/or average the above mentioned signals. As a result, examples of several waveforms generated by SimPac I are shown.

1 INTRODUCTION

The auditory evoked potentials (AEP) play a fundamental role in the audiology practice. The capacity of capturing electric potentials generated in response to acoustic stimulations resulted in many relevant applications to the oto-neurologist (Katz, 1999). AEPs are classified in agreement with its latency. Potentials of short latency occur in up to 10 ms after the auditory stimulation. Middle latency potentials occur between 10 ms and 100 ms after the stimulus, and long latency potentials are registered after 100 ms from the stimulus. Short latency AEPs are known by the acronyms BAEP – Brainstem Auditory Evoked Potentials, BERA – Brainstem Electric Response Audiometry or ABR - Auditory Brainstem Response (Chiappa, 1997). The electrocochleography (EcochG), used for cochlear evaluation, is also considered a short latency AEP. ABR is used for evaluation of the brainstem

integrity and also for objective audiometry. Middle latency evoked potentials are identified with the acronyms MLR or MLAEP (Middle Latency Auditory Evoked Potential). MLAEP is indicated to evaluate dysfunctions that could commit the hearing pathways located between the brainstem and the primary cortex.

P300 and MMN (Mismatch Negativity) are the most used long latency AEPs in the clinical practice. P300 presents a positive peak around the 300 ms latency and using it makes it possible to obtain, in only one test, information about the activity of the transition thalamus-auditory cortex, the own auditory cortex, about the hippocampus, hearing attention and cognition. P300 is elicited through a "rare paradigm", in which a few "rare" stimuli happen randomly in a series of "frequent" stimuli. The difference between both can be the intensity or the frequency. The MMN test uses also rare and frequent stimulus, but the result reflects the central processing capacity (Caovilla, 2000).

ECG is certainly the most known bioelectric signal generated by the human body. That signal is captured and analyzed for use in clinical diagnosis, surgical accompaniment and rehabilitation. Several types of ECG simulators exist, able to simulate changes in amplitude, heart beat frequency and many types of arrhythmias (Prutchi and Norris, 2005). They find application in the project of new monitors and in the preventive and corrective maintenance.

The perfect corporal balance is very important for the living organism orientation in the environment. That balance widely depends on the vestibular system, which acts in cooperation with the visual system to maintain the vision focus during head movements. The cerebral system that makes it possible is known as vestibulo-ocular reflex (VOR). The electric evaluation of VOR is done through the electronystagmography exam (ENG) or by its variant, the vector-electronystagmography (VENG) (Castagno et al., 1994). The evaluation of ENG/VENG is based on the registration and analysis of the nystagmus, that is, the reflex ocular movements which happen when the labyrinth receive caloric or rotational stimuli.

The proposed Patient's Simulator was called SimPac I and incorporates the technological solutions used in the previously developed prototype SPEA (Freitas et al., 2006). SimPac I has the purpose of serving as a tool for development, validation, adjustment and maintenance of AEP, ECG and ENG/VENG equipments.

2 MATERIALS AND METHODS

SimPac I is able to generate in two channels all of the short, middle and long latency AEP waveforms mentioned in the introduction. The morphology of those signals was shown in a previous paper (Freitas

et al., 2006). Real signals of AEP were scanned to obtain 500 samples for each one, and after they were digitally processed in order to ensure the use of whole the dynamic range of the 12-bit D/A converters present in the simulator. Figure 1 contains the blocks diagram of SimPac I. The main hardware component is the microconverter (μ C) ADuC841 (Analog Devices, 2003), whose CPU is compatible with Intel's 8052, modified to execute instructions to 20 MIPS peak. The simulator does not require external memories, since it uses only the μ C internal program FLASH and internal RAM. ADuC841 is responsible for waveforms generation using DDS technique (Digital Direct Synthesis), starting from the sample tables stored in FLASH memory (Grover and Deller, 1999). Energy is provided by four NiMH 1.2V batteries, or by 5 V external source. The microconverter requires 5 V supply while the analog circuits are supplied by a symmetrical voltage of ± 5 V. Those voltages are generated by a circuit which combines boosts with switching capacitors and inverters. The complete power circuit uses two chips LM2621 (National), one ADM8660 (Analog Devices) and one ICL7662 (Maxim), including also a soft starter commanded by μ C. User's interface was remodeled regarding SPEA. The rotary encoder and the push-buttons were substituted by a membrane keyboard and a graphic liquid crystal display (GLCD) with 8 kpixels. The GLCD driver is made by the μ C itself, through the ports P0 and P2.

The effective AEP simulated signal generation depends on an external request, since the averaging operation demands synchronism between auditory stimuli and electric signal acquisition. That external event consists of applying a voltage border in the "external trigger" input. The direction of the border, rise or fall, can be programmed in the simulator.

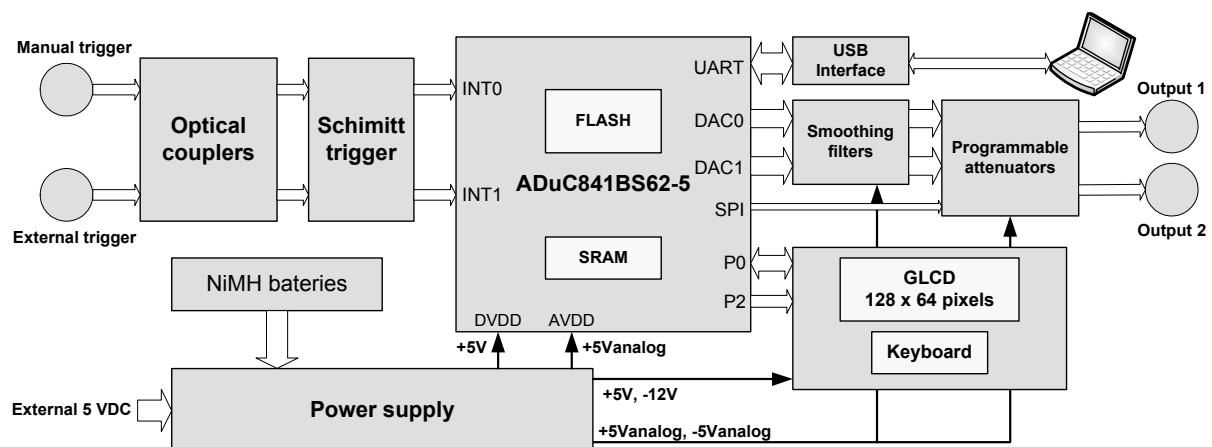


Figure 1: SimPac I blocks diagram.

For test and continuous type signals generation, a button named "manual trigger" was included. In any trigger type, manual or external, the pulse passes through a Schmitt trigger circuit that gives to the μC an interrupt signal free from bouncing.

Manual trigger causes the INT0 core interrupt, while external trigger causes the INT1 core interrupt.

The D/A conversion rate is set by an internal μC timer, which is reprogrammed in agreement with the selected signal to be generated. Each D/A output is followed by a conditioning circuit that filter (low-pass reconstruction) and reduce the signals to the real voltage levels observed in the human body signals. The amplitude adjustment is made by an attenuator of 120 dB in range and 0.5 dB in resolution, programmed through the μC SPI port.

2.1 Software

When the equipment is turned on, the software exhibits a greeting message in GLCD, which is followed by the main menu. Starting from that menu the user can select the signal to be simulated. For each signal, a specific sub-menu is exhibited allowing adjustment of parameters as frequency, amplitude, heart rate, angular velocity and others. When the generation of a signal associated with the external trigger is requested, the first task is to program the reference timer with the corresponding value for the signal's sample rate. In the interrupt INT1, the timer is triggered and its service routine is responsible for the DDS signal generation. EcochG, ABR, MLR and LLR are reproduced in the same way: at each INT1 interrupt, a finite loop transfers the samples stored in FLASH memory to the D/A converters. The software routine which generates P300 and MMN signals alternate the reproduction of frequent and rare signals, stored in different tables, to simulate the physiologic response to stimulation. From each INT1 interrupt, the software establishes which signal should be generated. The signals generation sequence is established through an oddball table also stored in FLASH. For generation of the ECG signals, the start is given by the manual trigger button. The timer defines the D/A conversion rate and the different heart beat frequencies are simulated varying the pause among two groups of complex P-QRS-T and the T duration itself. For ENG signals the technique is similar to that of ECG, however the variations of angular velocity are simulated changing the sweeping step of the tables recorded in FLASH memory. The parameters used on the SimPac I software regarding signal characteristics are presented in Table 1. The

different combinations of periods and D/A conversion rates are obtained programming the reference timers prior to starting the generation of each signal.

The SimPac I embedded software was developed in C language with aid of the $\mu\text{C}/51$ V1.20.04 programming tool (Wickenhaeuser, 2005). After the code compilation, the software was downloaded to the program FLASH memory using WSD 6.7 (Analog Devices), and tests were made, which are showed in next section.

Table 1: Main characteristics of simulated signals.

Signal	Amplitude	Period/frequency	D/A Rate
EcochG	0.5 μV typical	5 ms	100 ksps
ABR	1 μV typical	10 ms	50 ksps
MLR	3 μV typical	50 ms	10 ksps
LLR	5 μV typical	500 ms	1 ksps
P300	5 μV typical	500 ms	1 ksps
MMN	5 μV typical	500 ms	1 ksps
ECG	0.5-1-2 mV	30-60-120-240 BPM	500 sps
ENG	0.1-0,5-1-2 mV	1-125 degrees/s	500 sps
Sine	0.5-1-2-10 mV	0.05-0.1-10-50-60-100 Hz	500 sps
Square	0,5-1-2-10 mV	0,05-0,1-10-50-60-100 Hz	500 sps

3 RESULTS

The ADuC841 was welded on the LQFP-to-DIL adapting board showed in Figure 2, developed to facilitate the access to the microconverter pins.

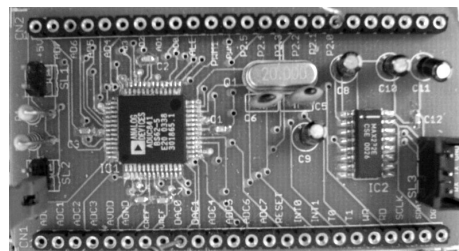


Figure 2: Adapter board from LQFP to DIL used in the prototype, evidencing the ADuC841 μC and the serial download interface to internal FLASH.

The other prototype components were mounted on a universal pre-drilled board, and the whole circuit was conditioned in a plastic box (Phoenix Mecano/BOPLA), as it can be observed in Figure 3. SimPac I prototype was exhaustively tested with a commercial AEP equipment (Contronic, 2007), presenting all AEP signals with synchronism, amplitude and timing as expected.



Figure 3: SimPac I layout.

Some of these signals are presented through the software ATC Plus version 2.1.59 (Contronic, 2007a), and they are shown in Figures 4 through 6. It is possible to note the perfect repetition of the AEP signals generated by SimPac I.

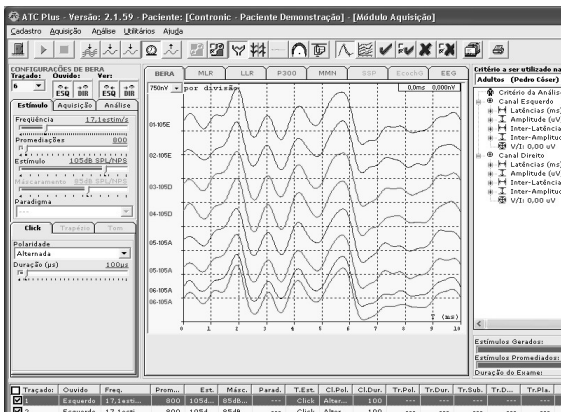


Figure 4: Simulated ABR.

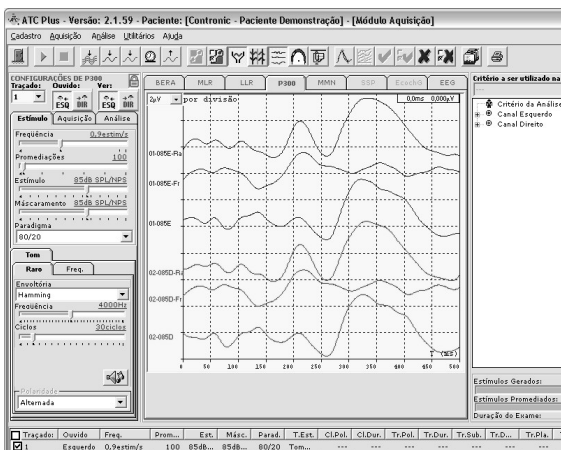


Figure 5: Example of simulated rare, frequent and resulting P300 signals.

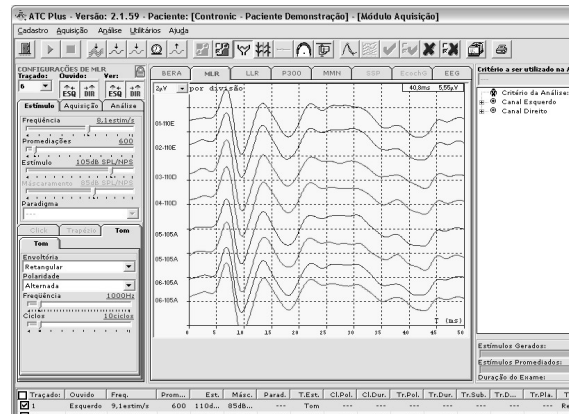


Figure 6: Simulated MLR (with VEMP) signal.

In Figures 7 and 8 some ECG and ENG signals from SimPac I can be seen, which were registered directly from the DAC outputs with the aid of a Rigol DS5102MA oscilloscope. These simulated ENG signals are being used in another project for validation of automatic algorithms intended to calculate the slow component of angular velocity of positional, caloric and rotary nystagmus.



Figure 7: Simulated ECG signal at 60 and 120 BPM.



Figure 8: Simulated ENG at several angular velocities, clockwise and counter clockwise.

4 DISCUSSION

SimPac I carried out all the expected basic functions. Several improvements were made regarding the previous prototype (SPEA): ECG and ENG signals, inclusion of performance signals intended to be used on amplifiers and filters verification (sine and square), inclusion of optical isolation in the external trigger input, new user interface using GLCD, function keyboard and soft starter. A circuit for USB communication was added to make easy the future inclusion of new signals to simulate.

For next version we intend to add a white noise generator to simulate the EEG signal in which the auditory evoked potential is immersed. That characteristic will allow extension of the tests of AEP equipments to the averaging quality.

Some simulators in the market generate waveforms through complex mathematical formulas, demanding digital signal processors for its implementation. SimPac I generates the waveforms from samples tables by DDS, and the execution can be made through a simple microconverter. The SimPac I main advantages are: the generation of signals that resemble those observed on biological systems, however with known amplitudes and latencies; the generation of signals with excellent repeatability; the substitution of the patient or volunteer during the development of medical equipments; and also in development, the elimination of undesired factors of difficult control, such as the electrode-skin impedance, other bioelectric signals like spontaneous EEG or EMG, and electromagnetic interference.

5 CONCLUSIONS

In this work we demonstrated the viability of creating an equipment intended to simulate AEPs of several types, ECG, ENG and performance test signals. SimPac I simulated signals were verified through a commercial system for AEP acquisition and a digital oscilloscope, showing reliability and precision in the requirements of synchronism, amplitude, timing and repetition. The use of this simulator can facilitate the software development and validation for processing AEP, ECG and ENG, as well as the hardware adjustment in production, and the preventive and corrective maintenance of electro-medical equipments.

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