Stimulator with arbitrary waveform for auditory evoked potentials

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Abstract. The technological improvement helps many medical areas. The audiometric exams involving the auditory evoked potentials can make better diagnoses of auditory disorders. This paper proposes the development of a stimulator based on Digital Signal Processor. This stimulator is the first step of an auditory evoked potential system based on the ADSP-BF533 EZ KIT LITE (Analog Devices Company – USA). The stimulator can generate arbitrary waveform like Sine Waves, Modulated Amplitude, Pulses, Bursts and Pips. The waveforms are generated through a graphical interface programmed in C++ in which the user can define the parameters of the waveform. Furthermore, the user can set the exam parameters as number of stimuli, time with stimulation (Time ON) and time without stimulus (Time OFF). In future works will be implemented another parts of the system that includes the acquirement of electroencephalogram and signal processing to estimate and analyze the evoked potential.

1. Introduction
The auditory evoked potential (AEP) gives audiometric examinations a better evaluation of the auditory pathway. In order to run such exams, it is necessary to record – directly from the scalp - the neural electrical activity of the networks responsible for the auditory pathway, as it responds to auditory stimuli (response evoked intermixed with the other activity in the electroencephalogram-EEG) [1,2].

Associated to the development of the necessary equipment for setting audiometer parameters, the application of exams that use the AEP technique has become widespread.

2. Auditory Evoked Potentials (AEP)
The auditory evoked potentials can be classified as transient and the steady-state. The transient AEP is that whose response has both a well defined beginning and end. In order to achieve this, the auditory stimulus has to be faced with a low rate enough so that the AEP to any given stimulus does not depend on any previous stimulus [3,4]. This kind of response is used in the BERA (Brain stem Evoked Response Audiometry) exam, in which the patient is stimulated with “click” sound, so as to test the integrity of his/hers auditory pathways.

Diagnostic tests done with transient AEP are, however, a difficult task, for they require a high number of stimuli so that a evoked response can be drawn from the patient. This response is then
compared to what is considered a normal pattern. This comparison of results and responses requires analysis by a qualified professional, which thus can make the diagnostic rather subjective.

Another fact that should be taken into consideration is that this type of examination provides a general analysis of the auditory pathways. In order to achieve a more specific analysis, it would be necessary to run the BERA exam on a single frequency at a time. Seeing that (to achieve a pattern response) several stimuli are required for each frequency under analysis, this technique can be seen as extremely time-consuming, a fact which turns it rather unviable for daily medical practices [4,5].

The steady state AEP (ASSR - Auditory Steady-State Responses) occurs when the stimulus is presented at a rate fast enough that the brain response to one stimulus is overlapped with the response to prior stimulus. The ASSR waveform elicited by amplitude modulation (AM) stimulus is simpler that at low repetition rates [6,7]. In order to analyze these responses can be used the Fourier Transform to evaluate whether the intensity of the modulated frequency is above a conceivable limit based on normality patterns. This way, it would be possible to develop an algorithm that automates the analysis of ASSR. This technique allows the simultaneous evaluation of different points of the basilar membrane, reducing testing time [5].

The audiometric physiology exam based on responses from evoked steady state is a relatively new technique; therefore its use in detecting hearing thresholds still is an open field of research. NEPEB (Núcleo de Estudo e Pesquisa em Engenharia Biomédica, UFMG’s Institute of Research in Biomedical Engineering), which researches evoked potentials – mainly the somatosensitive one – is developing a system that allows the recording of evoked auditory potentials, especially ASSR.

The system for ASSR consists of the following modules (see Figure 1):

- Generation of hearing stimuli.
- Presentation of the stimulus to the patient through headphones specifically designed for such a purpose.
- Register of the evoked potential in the head/scalp (by EEG).
- Signal processing for evaluation of the evoked responses.

This paper will approach the implementation of the module responsible for the generation of the auditory stimuli with an arbitrary waveform.

![Figure 1. Diagram of the auditory stimulation system.](image)

3. Material and Methods
The generation of the auditory stimuli will be focused on the main waveforms used in AEP: AM tones, short duration pulses (“clicks”), sine waves, burst tones and pips tones.

To generate these waveforms the following hardware resources – found in Analog Devices (USA) ADSP – BF533 EZ – KIT lite TM development kit [8] – will be used:
Blackfin ADSP – BF533 32-bits processing machine [9].
AD1836 CODEC for digital-analog conversion, which will be made by a sampling rate of 48,000 samples/sec, and samples will be converted at a 24-bits resolution[10].
Amplification auditory circuit based on AD8606A operational amplifying precision machine that provides up to 6 output channels [11].
Serial interface communication (UART) that follows RS-232 tension patterns.
32MB SDRAM memory, and 1MB flash memory.

The Blackfin processing machines have the necessary features for the accomplishment of the research project in question, for it has high capacity for processing calculations and mathematical models of larger complexity. This fact allows the system to generate “real time” waveforms.

Another great contribution of this kit can be found in its ability to generate trigger signals. Such ability is extremely important to the collecting of EEG signals to be synchronized with the stimuli generated (Figure 1), a situation which allows the AEP contained in the EEG to be measured.

Some of the features of the ADSP – BF533 processor are:
- 32-bits processing machine;
- DSP core clock– 600 MHz;
- Floating point operation;
- Core with 2 MACS of 16-bits, 2 ULAS of 40-bits, and 1 shifter of 40-bits;
- 148 Kbytes Inter RAM;
- DMA controller;
- Generic I/O interfaces;
- Internal hardware for UART communication.

ADSP-BF533 has the software Visual DSP++ as its IDE - Interface Development Environment. This software uses the C, C++ programming languages, and the processor assembly. Visual DSP++ was used to develop the firmware (a software dedicated to the hardware of the project), whose main functions are: to digitally generate waveforms and trigger signal, to control the CODEC in the digital-analog conversion, to run the protocol of auditory stimulation, and to provide the serial communication with the computer.

The control parameters of generated waveforms can be adjusted by the user through a C++ language software program that will provide a graphic interface between the DSP and the user, allowing the selection of parameters such as: waveforms, stimuli intensity, stimuli frequency and even the protocol in which these stimuli will be run.

4. Results
The prototype (see Figure 2) can generate stimuli with different waveforms as pulses of short duration (“clicks”) and AM tones that can be placed in the following parameter variation:

Short duration pulses (“clicks”)
- Sound level: from 20 to 90dB in steps of 1dB.
- Pulse width: 50us to 1ms in steps of 10us;
- Stimulation frequency: 1 to 100Hz in steps of 1Hz.

AM tones
- Carrier frequency: of 500 up to 8000Hz with steps of 1Hz;
- Modulation frequency: of 20 up to 150Hz with steps of 1Hz.
- Modulation depth: of 0 up to 100% in steps of 1%;
- Sound level: from 20 to 90 dB in steps of 1dB.
The graphic interface (see Figure 3) has two fields: the first one on the right side shows waveform of the stimulus that will be generated when the button “Enviar”- send - (bottom left on the window screen) is pressed. The second field, on the left side, has options for the selection of stimulus parameters, as well as of the exam protocol (stimulation time; interval between stimulation epochs, number of stimuli) that can be chosen by the user. The wave graph is automatically updated as the user alters the parameters.

Figure 2. Prototype developed by Biomedical Engineering Laboratory of UFMG.

Figure 3. Graphic Interface. AM tone waveform with modulation depth equal to 1, modulation frequency equal 50Hz and Carrier frequency equal to 1000Hz.
Illustrations 4-9 show the measurements of the stimuli in AM tone, click, sine wave, pip tone and burts tone, respectively. Such waveforms were obtained from a digital oscilloscope (TDS – 1002 by Tektronix) connected to the audio outputs of the DSP kit.

**Figure 4(a).** AM tone with carrier frequency 1kHz and modulation frequency equal to 50Hz.

**Figure 4(b).** AM tone with carrier frequency 4kHz and modulation frequency equal to 50Hz.

**Figure 5(a).** Click with frequency equal to 40Hz and pulse width equal to 0.1ms.

**Figure 5(b).** Click with frequency equal to 20Hz and pulse width equal to 4ms.

**Figure 6.** Click stimulation with frequency equal to 20Hz and pulse width equal to 0.2ms.
5. Discussion and Conclusions

The ADSP-BF533 system, along with the graphic interface, was shown as very versatile for the prototype development of hearing stimulator.

Such versatility is mainly seen in the several variations that can be obtained for a same type of wave. This way the user, for example, can generate AM tones based on different combinations of the parameters that make up this waveform.
Moreover, the prototype’s interface is user-friendly, a feature that allows the user to clearly identify all parameters that will be transferred to the hardware in order to generate the stimuli. It also (previously) shows the wave that will be generated.

As it has already been mentioned, the study developed so far is part of a research project that aims at analyzing the electric neural activity triggered by auditory stimuli.

This study will proceed with the calibration of the stimulator by using Telephonics TDH-39 supra-aural headphones. In this type of headphone, the relation between the input signal and the sound pressure generated in the output is known, a fact which allows the stimuli intensity to be adjusted via software. Also, the stimulator will be connected to a EEG system with specifications for registering the evoked potential. Finally, the processing of the EEG signals for obtaining evoked potential will be implemented.

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