Implementing a Signal Processing Subsystem to Detect Stimulated Otoacoustic Emissions Using the TMS320C31 DSP

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Abstract

As screening programs for neonatal hearing become more common, there is a need for automatic signal processing methods to classify measured signals and results. Transient click-evoked otoacoustic emissions (TEOAE) are becoming an important tool for screening, especially of hearing in newborn children, because this objective technique requires little cooperation from the patient. The principal problems of this method are difficulties in detecting and identifying emissions in the acoustic response signal from the inner ear requiring a large number of calculations. Results are immediately available during the screening procedure.

As proposed here a system based on a digital signal processor (DSP) should be used for this purpose. In the first stage, statistical algorithms reduce noise and calculate signal and noise energy. The next steps are Fast Fourier and Wigner Ville transforms, digital filtering, and correlation analysis. The system includes a Texas Instruments (TI™) DSP TMS320C31 with added AD and DA converters. Data acquisition, click generation and preprocessing are located on the measurement part of the system. Most important benefit of this solution is the combination of high power computing facilities for mathematical algorithms on DSP to reach a high sensitive in screening with comfortable data and result presentation on the PC.

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Introduction

Stimulated otoacoustic emissions appear in the human ear. The presence of stimulated otoacoustic emissions is an expression for the faculty of human hearing, especially with neonates and young children. There are brain-stem-evoked electric responses, spontaneous otoacoustic emissions, and stimulated otoacoustic emissions. In this report, we will describe a system to detect stimulated otoacoustic emissions and distinguish them from other signals.

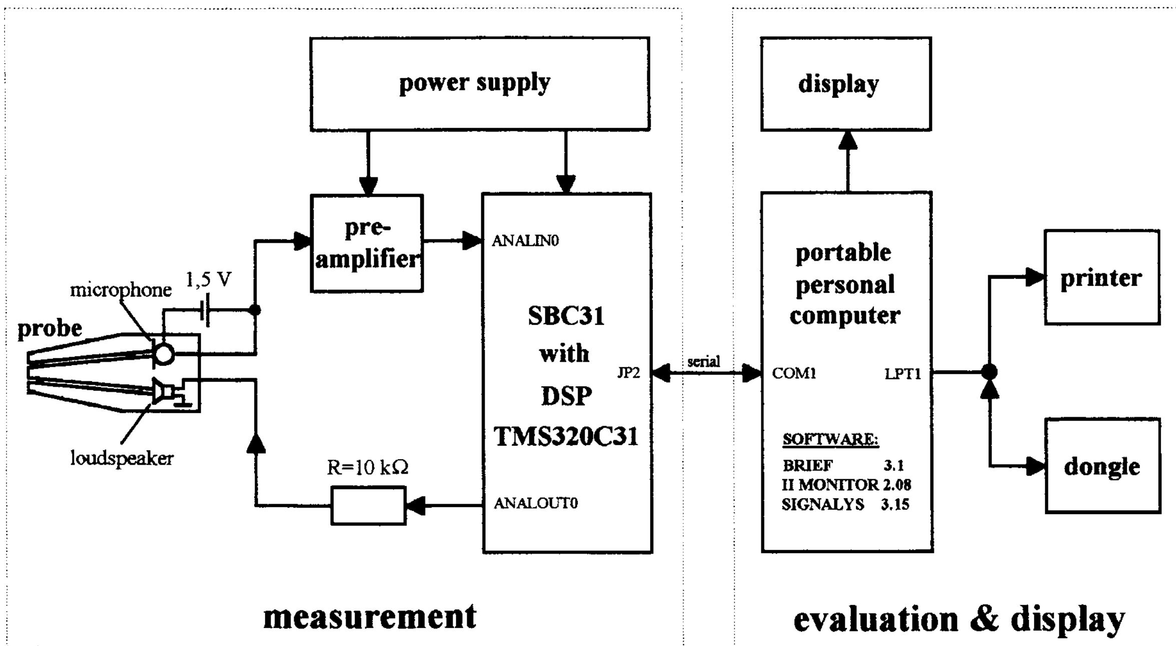
Otoacoustic emissions measured in the ear canal are acoustic energy leakage from the biochemical reactions of a healthy cochlea. They may occur spontaneously or be evoked by acoustic stimulation. Otoacoustic emissions appear to originate from within the cochlea and propagate through the middle ear structures to the external auditory meatus. It is there, with the aid of a sensitive microphone and signal analysis techniques, that they may be measured.

To measure otoacoustic emissions, a stimulus signal, usually clicks, is given over the loudspeaker into the ear of the test person and the recording of the response signal is captured using a microphone. After a click, the otoacoustic emissions that occur in a healthy ear have a latency of 2 ms to 20 ms. A number of response epochs must be averaged to improve the signal-to-noise ratio and produce a clear waveform. Mathematical methods are used for the evaluation of the recorded response signal.

The Measuring System

The measuring system used to detect otoacoustic emissions consists of five parts, as illustrated in Figure 1: a measuring probe with microphone and loudspeaker, a low-noise preamplifier, a digital signal processing system based on a digital signal processor, a portable personal computer and a power supply.

Figure 1. Block Diagram of the Measuring System used to Detect Otoacoustic Emissions



The signal processing system consists of a stand-alone processor card SBC31 from Innovative Integration. This system is based on the Texas Instruments TMS320C31 DSP. The SBC31 has an analog input section with a dual analog-to-digital converter (ADC) DSP102 (Burr Brown). The analog output section has two dual digital-to-analog converters (DAC) DSP202 (Burr Brown). A Zilog 85C30 UART provides serial communication support for the SBC31. The memory configuration of the SBC31 consists of 32K words of program SRAM.

The loudspeaker in the probe is connected to the analog output of the SBC31. It emits the stimulus signal into the ear of the test person. A resistor is used to protect the loudspeaker from signals with high amplitudes. The microphone in the probe records the response signal. The recorded signal is applied to the low-noise preamplifier with an amplification factor of 10. This signal is then applied to the analog input of the SBC31.

The power supply of the preamplifier and the SBC31 uses NiCad accumulators. The SBC31 is connected to the portable personal computer via serial ports. The software BRIEF 3.1 and II Monitor 2.08 is supplied with the SBC31. Also a dongle is supplied with the SBC31, which must be connected to the parallel port, LPT1, of the personal computer. The dongle is required to enable the program II Monitor 2.08 to function properly.

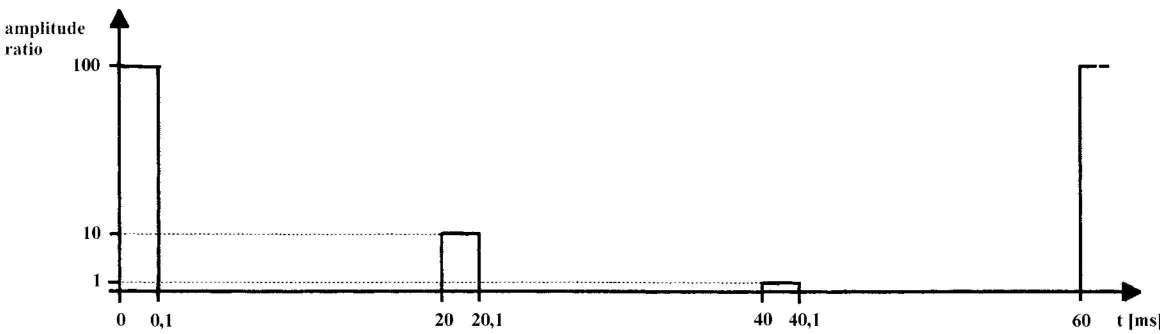
The program II Monitor 2.08 facilitates the communications between the personal computer and the SBC31. This software is required to perform downloads and to start the measuring program, OAE. The software also allows the II Monitor 2.08 to control the recorded data after a measurement. The software BRIEF 3.1 was used to create the measuring program, OAE, which controls the measurement of the otoacoustic emissions.

The SIGNALYS 3.15 software was used to evaluate the recorded responses and to enable a detailed analysis in the time domain and in the frequency domain.

The Execution of the Measurement

To measure otoacoustic emissions, a stimulus signal is emitted over a loudspeaker into the ear of the test person. The stimulus signal consists of a sequence of clicks, as illustrated in Figure 2.

Figure 2. One Period of the Stimulus Signal

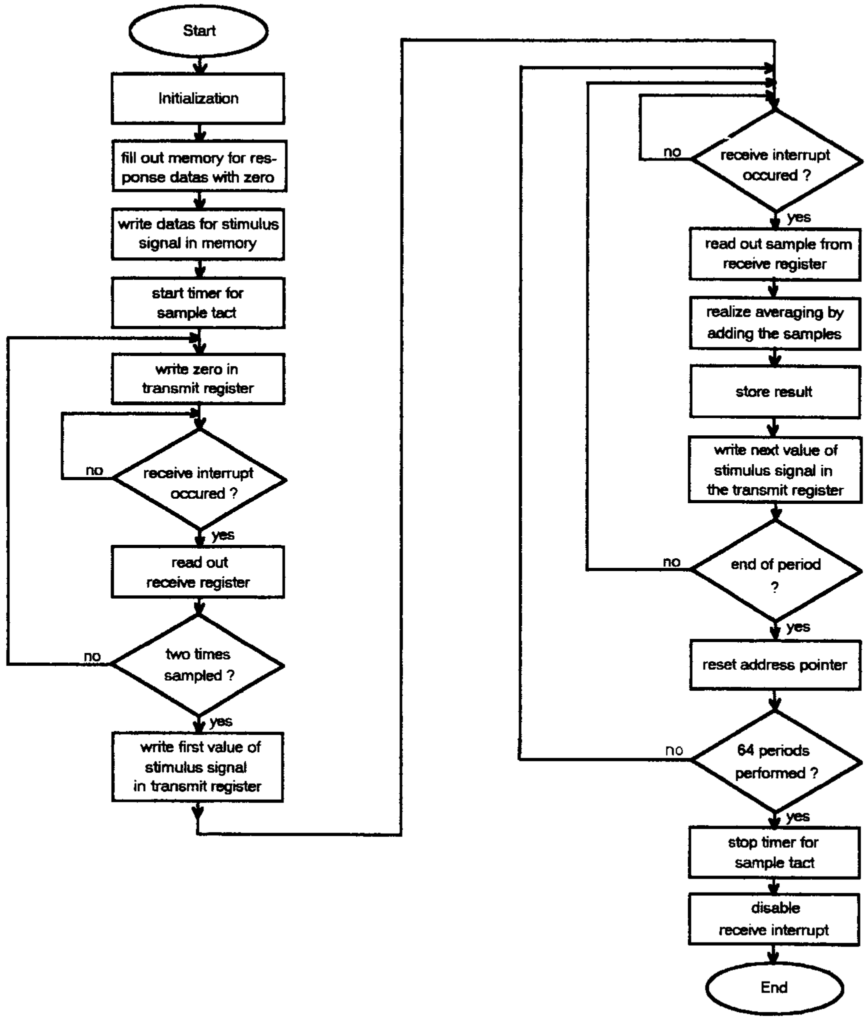


There are three clicks in the sequence each with different amplitudes. The amplitude ratio of the clicks is 100:10:1. Every click has a length of 100 µs. The clicks will be emitted every 20 ms. Between two clicks there is a time of silence with a length of 19,9 ms (=20 ms-100 µs). During this time the response signal of the click, i.e. the otoacoustic emissions, can be recorded.

To realize the stimulus signal, a sample frequency of 20 kHz is used. The response signal record has the same sample frequency as the stimulus signal. With this sample frequency, 400 values are required for one click with silence. The first two values represent the real click and the next 398 values are zeroes. For one period of the stimulus signal with three clicks, as shown in Figure 2, 1200 values are needed. This stimulus period will be repeated 64 times and the recorded response data are averaged to improve the signal-to-noise ratio and produce a clear waveform.

The OAE program was created to control the measurement. This program was written in assembly language, using BRIEF 3.1. The flowchart of the program OAE is shown in Figure 3.

Figure 3. Flowchart of the Program OAE



The SBC31 and the DSP are initialized first when the OAE program is started. Then the memory locations for the response data are zero filled. Next the 1200 values for one period of the stimulus signal will be written in a defined memory location. At this point the OAE program enables the timer to provide the sample tact. The first two transmitted samples are zero and the first two received samples are ignored. This is necessary, because this data is not from the current measurement. They were stored in the ADC from an earlier measurement or they are random values.

Now the real measurement of the otoacoustic emissions can begin. With every sample tact the data of the stimulus signal will be written in the transmit register and will be sent to the loudspeaker. At the same time, the response signal will be recorded with the microphone and the received samples of the response signal will be stored in the defined memory location. The samples will be averaged at every period. After 64 averaging periods the timer for the sample tact will be stopped, the receiver interrupt will be disabled and the measurement is complete.

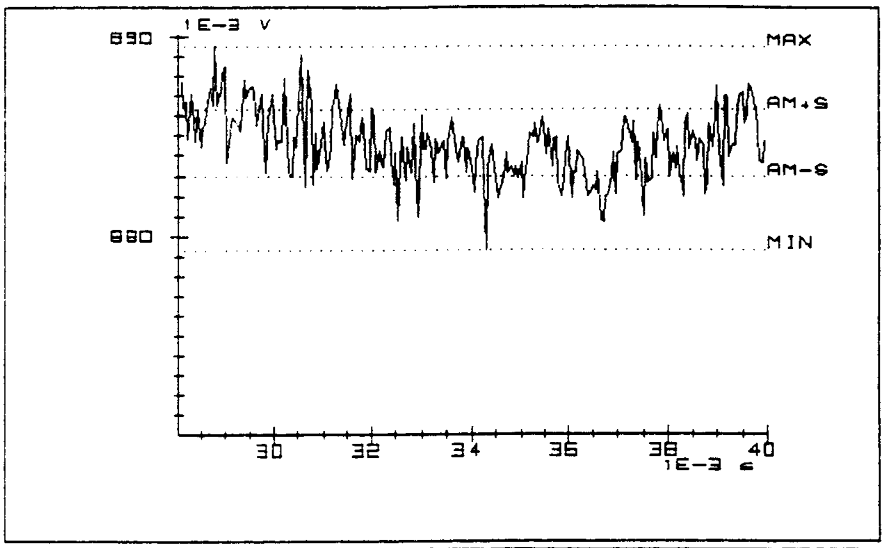
Evaluation of the Measurement Results

The SIGNALYS 3.15 software is used to evaluate the recorded response signals. To use this software for the evaluation, it is necessary to save the recorded samples of the response signal as a file after every measurement. The software II Monitor 2.05 offers a feature to save any range of samples as a file.

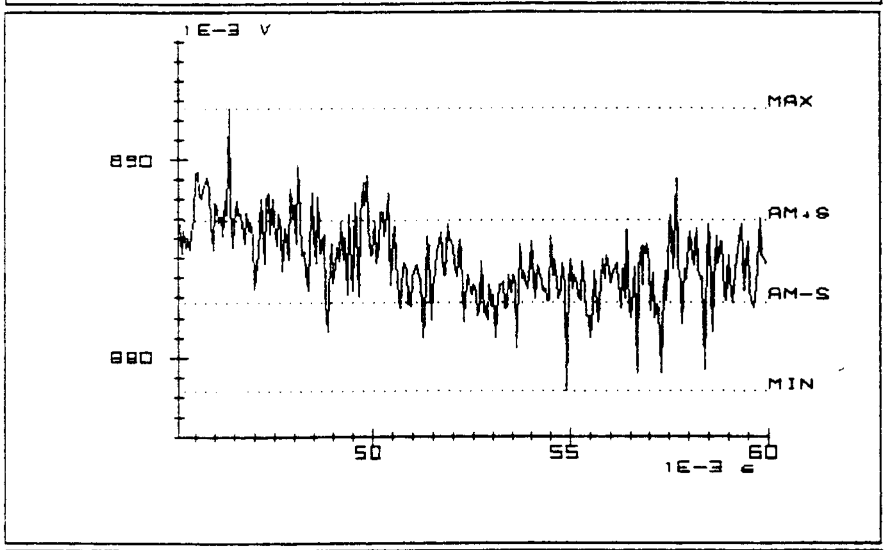
With SIGNALYS it is possible to display the response signal as a graph. A typical example of such a graph is shown in Figure 4. The graph shows the responses of the three clicks from Figure 2. Because of the echo after the click the full range of time between two clicks is not displayed.

Figure 4. Stimulated Otoacoustic Emissions

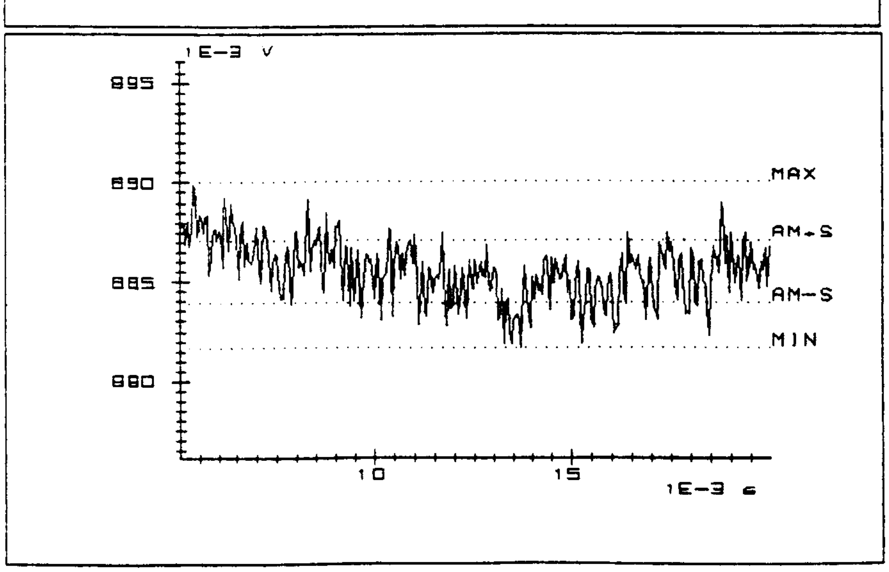
Time: 28 –40 ms
Response of 1st Click



Time: 45 – 60 ms
Response of 2nd Click



Time: 5 - 20 ms
Response of 3rd Click



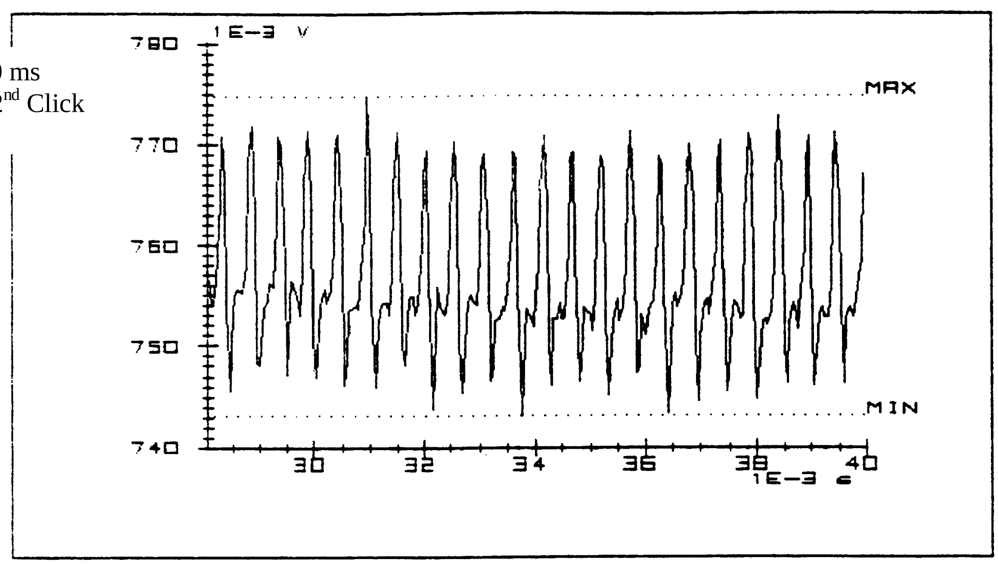
SIGNALYS offers the option to calculate the standard deviation and the variation range of every response. In addition, it can calculate the cross-correlation between two responses. For comparison we have done measurements without any stimulus signal in the ear. A comparison of the standard deviations and variation ranges between responses with and without click shows that the responses with a click have greater values than do the responses without a click. We have correlated two responses with a click and a response with a click with a response without a click from the same ear. Because of the reproduction of the otoacoustic emissions in the same ear, the correlation between two responses with a click gives a better result than the correlation between responses with and without click.

The results of these analysis methods show that the recorded response signals after a click are really stimulated otoacoustic emissions.

Also, we could record in some cases spontaneous otoacoustic emissions. Spontaneous otoacoustic emissions occur in some ears without an external stimulus signal. The difference between stimulated and spontaneous emissions is that spontaneous otoacoustic emissions oscillate with a near-constant frequency. A typical example of spontaneous otoacoustic emissions is shown in Figure 5.

Figure 5. Spontaneous Otoacoustic Emissions

Time: 28 – 40 ms
Response of 2nd Click



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