Towards an Ultra-High Resolution Signal Converter for Electroencephalogram Monitoring

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Background: Electroencephalography (EEG) is an important tool in understanding the effects of anesthesia on the central nervous system. The EEG signal itself has immense non-linear complexity, and is known to contain fine structure such as spindles [1] that are reflective of anesthetic state. It is possible that other, more subtle, features of the EEG are presently missed due to the limitations of current EEG data acquisition technology.

Objective: Our goal is to facilitate new insights into the effects of anesthesia by vastly improving the performance of the EEG data acquisition subsystem and implementing corresponding novel digital processing algorithms.

Methods: We have designed a custom sigma-delta Analog to Digital Converter (ADC) using state-of-the-art design and simulation tools. The new ADC employs advanced noise shaping concepts to move noise away from the clinically relevant regions of the signal spectrum, thereby obtaining an effective resolution considerably greater than previously seen. An ultra-low-noise differential front end will send signals to the ADC from the patient forehead (Figure 1a), and the bitstream output of the ADC processed by a custom field programmable gate array (FPGA) on a Xilinx Zync™ System-on-Chip board. FPGA logic will be used to compute and output trends to the Zync ARM host processor for display and further analysis.

Results: The analog circuit simulation of the first prototype design has been completed using manufacturer component models, and shows performance to be approaching 140dB (Figure 1b), better than any ADC currently available. With a root–mean-square (RMS) error of only 268nV on a 1KHz reference sinusoidal signal of +/-2.4V (1.7V RMS) amplitude, this corresponds to resolving the signal to 1 part in 30,000,000. This is approximately 300x better than the theoretical maximum resolution of 16bit converters used in current EEG equipment.

Conclusions: The application of advanced signal converter technology is found to potentially improve EEG signal acquisition resolution by almost three orders of magnitude. Work is in progress to implement a discrete version of the medical ADC and an FPGA backend, with a longer-term view to realize a fully integrated single-chip medical ADC for a next generation of ultra-high resolution anesthesia monitoring systems.
Figure 1: Medical sigma-delta ADC for EEG monitoring: EEG setup (a) and simulation results (b).