Neuronal Recorder Implementation With Envelope Detector for Fidelity and Linearity

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***Abstract*—Neuronal recorders of high-performance and low-power are needed for many embedded biomedical devices and the next-generation cyber-physical systems to capture the low-voltage, low-frequency brain signals. In this paper, an envelope detector implementation is reported that outperforms the conventional 2nd order band-pass filter (BPF). Simulation of the envelope detector outperformed the BPF by 2 dB for fidelity and 2.25 dB for linearity, but performed 0.4% worse for THD+N. Implementation of the envelope detector provided satisfactory performance with 2.8 dB fidelity and 3.7 dB linearity attenuation. As envelope detector requires lesser area and power, it promises to be a viable alternative for miniature implementation of neuronal recorders.**

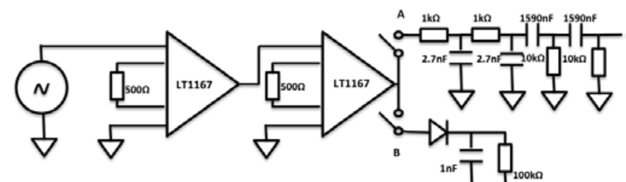

Fig. 1. Two stage amplification along with (A) 2^{nd} Order BPF and (B) envelope detector

I. Introduction

The neurons generate action potentials when they depolarize, with a typical intracellular potential of $-30mV$ to $70mV$ [1]. The extracellular recorder records the local field potentials (LFP) that ranges $50\mu V$ to $500\mu V$ in amplitude and from the $100Hz$ to the $3KHz$ in frequency. Intensive research is being conducted [1] to improve the recording mechanism that provides high performance but consumes low power and can be miniaturized to enable embedded neuronal recorder towards building the infrastructure for the next generation of Cyber-Physical Systems (CPS), [2]. The standard approach, as in [3] [4] , is first to use a pre-amplifier, using Instrumentation Amplifiers, followed by a Band Pass Filter (BPF) and then another amplification block for proper amplitude scaling that is fed to an Analog to Digital Converter (ADC).

To improve linearity and fidelity, after the pre-amplification an envelope detector is used instead of the BPF to *filter* the noise. This paper presents preliminary results for simulation and implementation with those two approaches.

II. Circuit design

The circuit presented in Fig. 1 is used for both the simulations and the implementation. The pre-amplification circuit consists of two Instrumentation Operational Amplifiers (LT1167, Linear Technologies, CA, USA). Some of its merit figures, [5], are variable gain from 1 to 10000, a CMRR of $90dB$, low supply current and a low voltage noise of $7.5nV/HZ$. A two stage amplification, each with a gain of 100 was chosen in order to have a higher amplification bandwidth of around the $100KHz$, while maintaining the desired gain.

The 2^{nd} Order BPF filter is shown in Fig. 1 that will be used for comparisons with the envelope detector , which can be seen in Fig. 1. Cut-off frequencies of $90Hz$ and $30KHz$ were chosen. The implementation of the filter with RC was used instead of LC because VLSI implementation, a due to the low current, the ohmic losses are low. Other amplification schemes, like a Butterworth using Sallen-Keys, was deemed to be too power/area consuming for the advantages it gives.

As for the envelope detector, as shown in Fig. 1, the values of $1nF$ and $10k\Omega$ gives a bandwidth, at $-3dB$, of $30KHz$. This frequency, which is a decade above the $3KHz$ signal that we want to record, was chosen because it was determined that the data can be analyzed using digital signal processing (DSP) in a later stage to find the response at higher frequencies than the typical ones and also lesser distortion on the band of interest.

III. Method

Two different tests were performed, a simulation and an implementation. The first step was to simulate the amplifier with the 2^{nd} order BPF and the envelope detector. As the envelop detector demonstrated superior performance over the BPF, the envelop detector was implemented.

The characteristics that were measured were fidelity, linearity, THD+N (Total Harmonic Distortion + Noise) and gain. Fidelity is the characteristics of a circuit to maintain an stable gain in a certain bandwidth in the input signal. On the other hand, linearity is the characteristic of a circuit to maintain an stable gain with a range of input voltages.

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A. Simulation

For the simulation two programs were used, the LTSpice v4.12 for the time and frequency response simulations and MATLAB R2011a for the frequency analysis and characteristics evaluation.

B. Implementation

To generate the bench/test signals of $100\mu V$, an attenuation circuit was needed as the output of the signal generator (Wavetek FG2 A) could not produce such a small amplitude. A sinusoidal signal was implemented in order to represent LFP signals in the order of $100\mu V$ at the input of the pre-amplifier. An Oscilloscope (Tektronics, TDS1001B) was used to sample and record the data so it could be analyzed using MATLAB to compute the same characteristics as in the simulation.

IV. Results

In Fig. 2 the fidelity results for the amplification circuit, BPF and envelope detector for both simulation and implementation, are shown. The frequencies tested were from $100Hz$ to $3kHz$ in stepts of $200Hz$ with an amplitude of $177\mu V_{pp}$. It can be noted that, the implemented results differ from the simulation ones due to the parasitic components, ambient noise and non/ideal behavior.

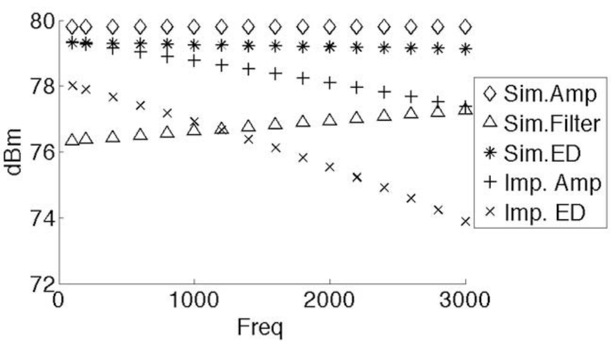

Fig. 2. Fidelity results for Envelope Detector (ED), Amplification(AMP) and Filter for Implementation (Imp.) and Simulation (Sim.)

As for the Linearity, Fig. 3 shows the results. The frequency was $1KHz$ and the input voltage ranged from $80\mu V$ to $355\mu V$. Again that implementation of the envelope detector is not as linear as in simulation.

In Table I, the average of the simulated results can be seen. For the average fidelity, the envelope detector attenuates the signal $1dB$ while in the linearity $0.9dB$ due to the ohmic loses. The BPF resulted in higher attenuation of $3dB$ for fidelity and $3.15dB$ in linearity. The THD+N, and as it was expected, with the envelope detector is reduced 0.4% while the filter is reduced by 0.8%.

In Table II the average of the implementation results can be observed. For the average fidelity, the envelope detector attenuates the amplifiedthe signal $2.8dB$ while in the linearity by $3.7dB$. As for the THD+N with the envelope detector resulted a reduction of 1.2% due to lower harmonic distorsion.

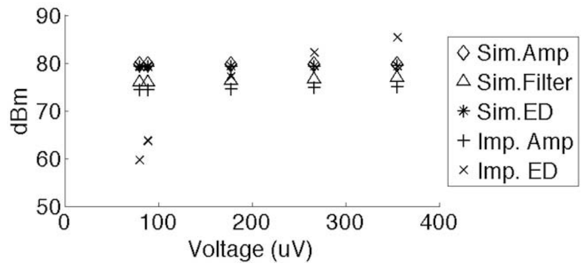

Fig. 3. Linearity results for Envelope Detector (ED), Amplification (AMP) and BPF for Implementation (Imp.) and Simulation (Sim.)

TABLE I
SUMMARY TABLE FOR THE RESULTS OF THE SIMULATION

	Amplifier	BPF	Envelope Detector
Fidelity	80dB	77dB	79dB
Linearity	80dB	76.85dB	79.1dB
THD+N	2%	1,2%	1,6%

TABLE II
SUMMARY TABLE FOR THE RESULTS OF THE IMPLEMENTATION

	Ampflifier	Envelope Detector
Fidelity	79.3dB	76.5dB
Lineality	79.7dB	76dB
THD+N	8,3%	7.1%

The implementation results for the envelope detector and the simulation results do vary, mainly because of the parasitic components as well as the use of standard SPICE models for resistors, capacitor and diodes. That can be clearly seen in the THD+N figures in Table I and Table II where in the implementation the values are higher than in the simulation. However, the relationship between is almost maintained.

V. Conclusion

A comparative study between two strategies for neuronal recorder implementation are presented. The simulation results showed that envelope detector outperforms the 2^{nd} Order BPF. Besides, the envelope detector consume less power and area than the standard 2^{nd} order BPF while maintaining an acceptable performance. The implementation results demonstrated applicability of the envelope detector for neuronal recorders.

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