IJBEM
Vol. 7, No. 1, 2005

Design and Development of a Novel EOG Biopotential Amplifier

Shubhodeep Roy Choudhury[1], S.Venkataramanan[2], Harshal B. Nemade[3], J.S. Sahambi[4]
Department of Electronics and Communication Engineering,
Indian Institute of Technology (IIT), Guwahati, INDIA

shubhod@iitg.ernet.in[1], svraman@iitg.ernet.in[2], harshal@iitg.ernet.in[3], jsahambi@iitg.ernet.in[4]

Abstract— **Electric potentials are generated across the Cornea and Retina of the eyes as a result of the movement of eyeballs within the conductive environment of the skull. This is referred to as the Cornea-Retinal Potential (CRP) and is the source of the Electrooculogram (EOG) signal. Since the occurrence of DC drifts and numerous artifacts along with power-line interference had made the EOG signal quite unattractive for pragmatic biomedical applications, our primary concerns were the elimination of these DC drifts and other artifacts while striving to maintain signal linearity. The paper describes the design and development of a novel EOG signal acquisition system that counters all the above mentioned problems making it suitable for both theoretical analysis as well as industrial applications.**

Keywords— **Biomedical Signal Processing, Biopotential Amplifier, DC Drifts, Electrooculogram (EOG) Signal, Signal Acquisition, Signal Linearity, Type II Chebyshev IIR Filter.**

I. INTRODUCTION

The generation of the Electrooculogram (EOG) signal can be understood by envisaging dipoles located in the eyes with the cornea having relatively positive potential with respect to the retina [1]. This EOG signal is picked up by a bi-channel signal acquisition system consisting of the Horizontal (H) and Vertical (V) channels. The placement of electrodes is shown in Fig. 1. The acquisition system employs Ag - AgCl surface electrodes for signal pickup which requires application of sufficient electrolyte gel to reduce the skin impedance. The EOG signal has a frequency range between DC and 38Hz and amplitude between 10 to 100mV. Current literature states that the EOG signal amplitude is merely dependent upon the position of the eyeballs relative to the conductive environment of the skull, though the signal has been found to be dependent on a few other factors in recently conducted research [2]. The EOG signal, like the other bio-signals is corrupted by environmental interferences and biological artifacts. Therefore the primary design considerations that have been kept in mind during the design of the EOG biopotential amplifier are proper amplification, sufficient bandwidth, high input impedance, low noise, stability against temperature and voltage fluctuations, elimination of DC drifts and power-line interference [3].

The main reason that has hampered proper utilization of the EOG signal in both industrial applications and theoretical analysis is the design of existing biopotential amplifiers.

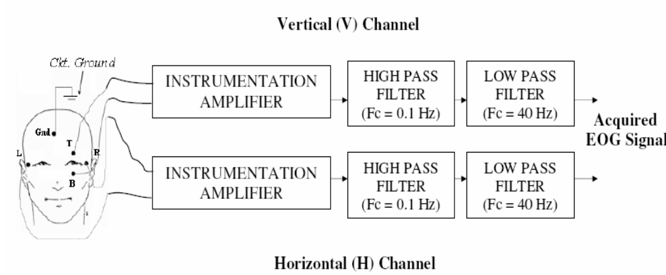

Fig. 1. Block diagram of the first phase of our EOG biopotential amplifier.

The design of EOG biopotential amplifiers till date, has either focused upon the elimination of DC drifts or upon maintaining signal linearity. The EOG signal acquisition system described in this paper efficiently handles this tradeoff between elimination of DC drifts and maintaining signal linearity over the EOG signal frequency range to minimize the loss of relevant information.

II. CONVENTIONAL EOG BIOPOTENTIAL AMPLIFIER DESIGN

The EOG signal has primarily served as the last alternative for biomedical applications till date, owing to the problems discussed earlier. Our analysis showed that the main factor was the design of the biopotential amplifier which acquires the EOG signal. Such a conventional design was implemented by us in the first phase of our work and this section discusses its construction and the challenges involved in its use in biomedical applications.

A. Conventional EOG Biopotential Amplifier Design

The first stage of any EOG biopotential amplifier is the instrumentation amplifier which provides the initial amplification while reducing the effect of signals such as power-line interference and skin muscle artifacts owing to its high Common Mode Rejection Ratio (CMRR). Two instrumentation amplifiers are employed for this purpose, one for each of the two channels [1]. Since the EOG signal content varies between DC and 38 Hz, a bandpass filter is used after the signal pickup stage, with cutoff frequencies of 0.1 Hz and 40 Hz as shown in fig. 1.

B. Need for Advancements in EOG Biopotential Amplifiers

The setup shown in fig. 1 was widely used to acquire the EOG signal for over a decade, before the need for using EOG in biomedical applications became acute, especially in the design of medical instruments for paralyzed people.

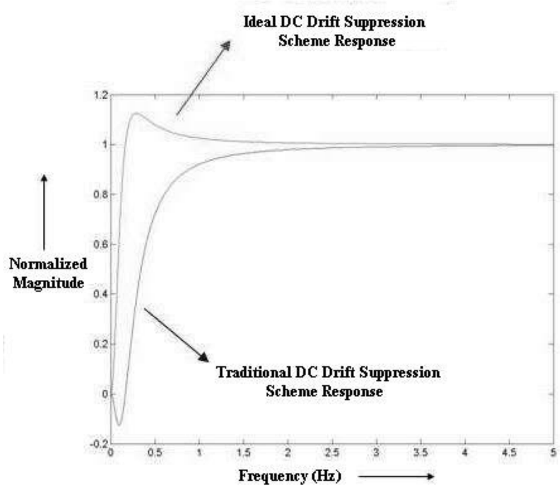

Fig. 2. Characteristics of the conventional DC drift suppression scheme and comparison with the ideal response

This in turn meant that, merely suppressing the effect of DC level drifts would not suffice, owing to the unreliability of such systems [4]. A comprehensive analysis of the challenges that were encountered while employing the conventional design of EOG biopotential amplifiers in practical biomedical applications are discussed in the following section.

III. EOG Biopotential Amplifier Design Analysis

The major problem associated with the conventional design of EOG biopotential amplifier is the continued presence of unpredictable DC drifts that tend to saturate the amplifier stages, even after high pass filtering [2]. This in turn renders the signal processing applications based on the conventional design of biopotential amplifiers unreliable [5]. The characteristics of both the DC drift suppression scheme used in such systems (with a cutoff of approximately 0.1 Hz) and the ideal response that achieves complete elimination of DC drifts are shown in fig. 2 for comparison. It is clearly noticeable that a sizeable amount of distortion is introduced between 1 Hz and 5 Hz in the conventional design of the EOG biopotential amplifier which makes the whole system non-linear. The other demerit of using mere high pass filtering is that it does not eliminate the DC drifts completely and they tend to occur quite frequently in the acquired EOG signal. In the next section, we shall observe how the novel EOG biopotential amplifier overcomes these two challenges. The electrical interference from the surroundings of the system are always present and the interference induced on the body common to the biopotential sensing electrodes is called the common mode interference [6] and its frequency is 50 Hz in India. This power-line interference is suppressed conventionally by the use of low pass filters of high orders, with a cutoff frequency of 40 Hz.

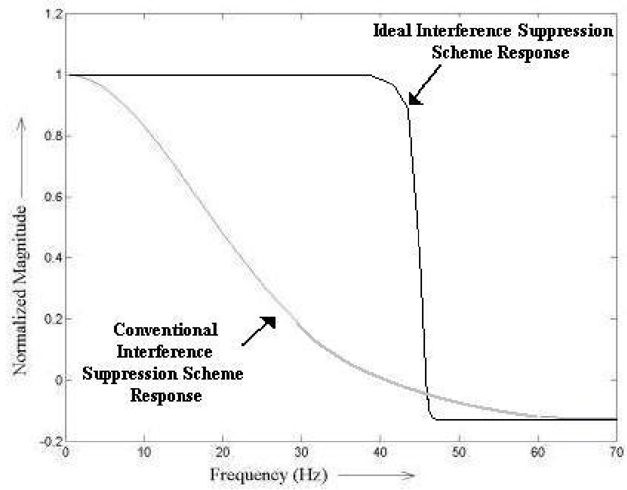

Fig. 3. Characteristics of the conventional power-line interference suppression scheme and comparison with the ideal response

The characteristics of such a conventional interference suppression scheme along with the ideal response that maintains EOG signal linearity is shown in fig. 3 for comparison. For appreciable suppression of the power line interference we should use a filter of high order and this is the drawback. Such filters have a very nonlinear response and when cascaded with the DC drift suppression filter they will make the whole system highly nonlinear.

Therefore, the conventional design of EOG biopotential amplifiers that also consists of the DC drift elimination and interference suppression systems is found to be highly inefficient, not only in failing to maintain the signal linearity but also in its inability to eliminate the DC drifts completely. The latter reason has been the main cause for sudden saturation of amplifier stages that has made EOG signal processing based application prone to error. Numerous methods have been proposed in the last decade for the exact determination of the moments when the DC drifts occur. But this makes the EOG biopotential amplifier a highly complex system, that too one that cannot be employed for theoretical signal analysis owing to the inherent non-linearity of such systems. Finally, effective suppression of the DC drifts, artifacts and interferences calls for the implementation of very sharp, high order filters, that not only increases power consumption, but also the fabrication cost. Owing to the unreliability, non-linearity and fabrication cost involved, EOG signal processing based applications are currently not popular and are seldom seen in the commercial market [2]. This is quite contrary to the fact that there is a huge demand for reliable and cheap EOG signal processing based applications in hospitals and the medical instrumentation industry [6]. This is the need for a new EOG biopotential amplifier that accounts for the problems of the conventional model.

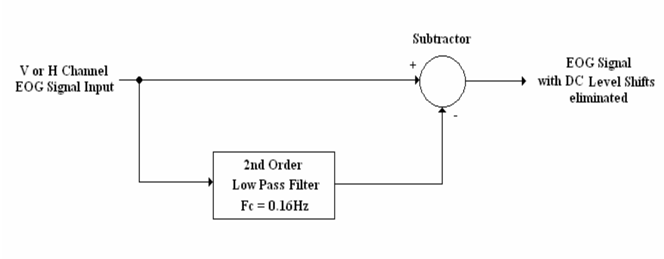

Fig. 4. Block Diagram of the DC drift suppression scheme used in the design of the novel EOG biopotential amplifier

IV. NOVEL EOG BIOPOTENTIAL AMPLIFIER DESIGN

The dual objectives of the EOG biopotential amplifier described in this section are to eliminate the effect of DC drifts and interferences and to maintain linearity in the frequency range of the EOG signal. The overall design of the EOG biopotential amplifier is unique and novel because it works intelligently with the above mentioned trade-off, while maintaining circuit simplicity, effective management of fabrication cost and achieving perfect reliability, hence making EOG signal processing attractive for both theoretical analysis and practical applications as well. This section discusses the design and analysis of the novel EOG biopotential amplifier and its advantages and applications are discussed in the following section.

A. DC Drift Elimination scheme

The block diagram of the DC drift elimination scheme used in the biopotential amplifier design is shown in fig. 4 and is used to eliminate the DC drifts completely instead of suppressing them as in the conventional design. The high pass filter that was employed in the conventional biopotential amplifier is replaced by a second order lowpass filter in the feedback path and a subtractor. The DC drift value that is acquired at the output of the lowpass filter is continuously given as input to the subtractor stage without much delay and is subtracted from the original signal, thus providing an effective solution to eliminate the DC drifts from the EOG signal.

B. Disadvantage of Drift Elimination Scheme and Solution

The drift elimination scheme described removes the DC component of the EOG signal also.

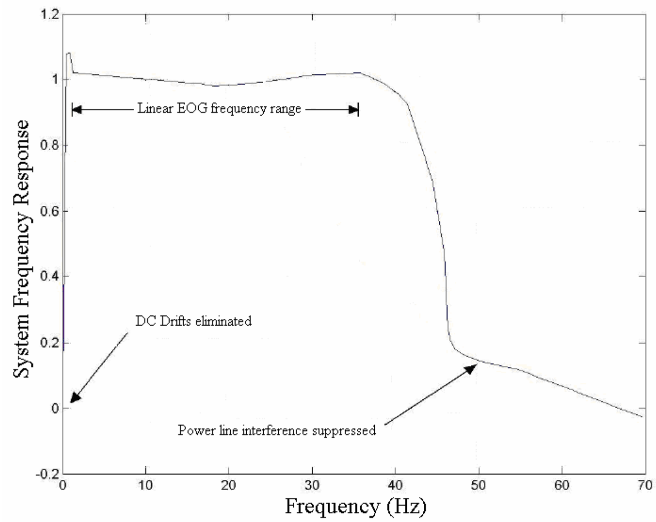

Fig. 5. The overall frequency response of the novel EOG biopotential amplifier. Notice DC drift and power-line interference elimination and linearity in EOG signal frequency range.

Therefore, even if the eye-balls are held at a particular position for some duration continuously, the signal output would not remain constant. Though this loss of the DC portion of the EOG signal may not hamper the working of many systems that employ EOG signal processing, it may be a potential source of error in systems that are eye-ball position dependent. This error can be corrected by using a set of ‘N’ D-latches to obtain the ‘N’ level quantized digital equivalent of the DC offset value. A/D and D/A converters are used before and after the set of D-latches. The digital drift value is updated using a push button that is manually controlled by the user. The overall frequency response of the novel EOG biopotential amplifier is shown in fig. 5 and the modified DC drift elimination scheme is shown in fig. 6.

C. Power-line Interference Elimination Scheme

The filter that is used to eliminate the 50 Hz power-line interference must possess linear response in the frequency range of the EOG signal and a small transition bandwidth. The EOG biopotential amplifier described in this paper suppresses the power line signal using a Type II Chebyshev lowpass filter that is constructed using a switched capacitor filter.

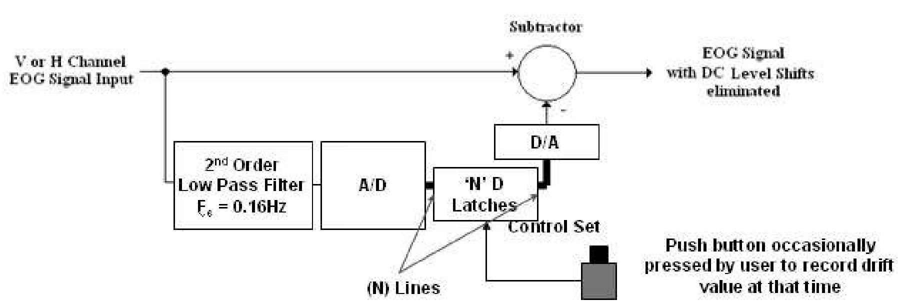

Fig. 6. The block diagram of the revised DC drift elimination scheme that preserves DC content of the EOG Signal.

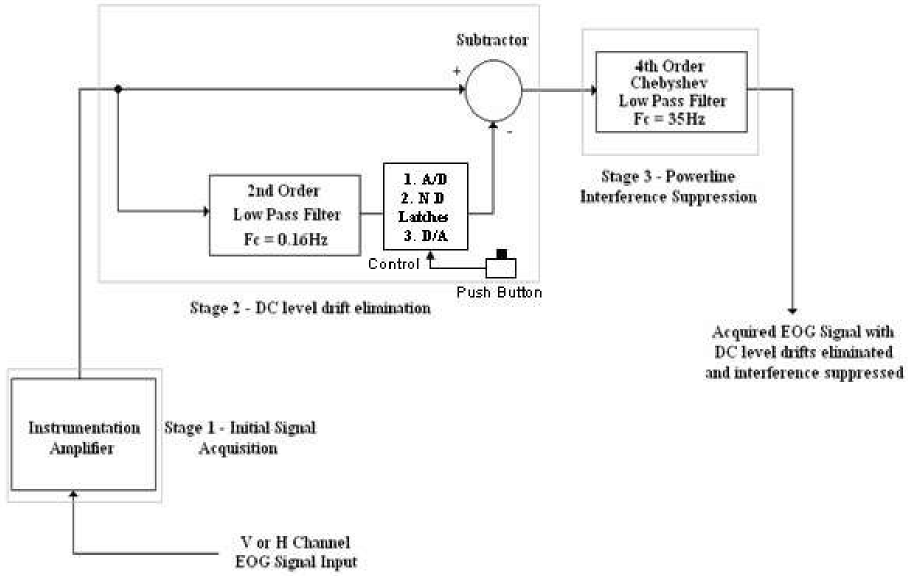

Fig. 7. The overall block diagram of the novel EOG biopotential amplifier including the DC drift and power-line interference

This is chosen because of the requirements of the system which demands linearity in the frequency range of the EOG signal, a very narrow transition band and maximum possible attenuation in the stop band, achieving all of which would be difficult with just discrete components. The Type II Chebyshev lowpass filter was preferred over other filters because it has linear response in its passband, has equiripple behavior in its stop band and the filter requires the least possible order for the same transition bandwidth when compared with other IIR filters of the same specifications. The overall block diagram of the novel EOG biopotential amplifier with the revised DC drift elimination and power-line interference suppression schemes is shown in fig. 7.

V. Results and Discussion

The novel EOG biopotential amplifier described in this paper was designed and found to acquire the EOG signal efficiently, while completely eliminating the DC drifts and interferences. This is seen as a major improvement over existing EOG biopotential amplifiers that have restricted EOG signal processing based applications from being widespread. The loss of the DC component of the EOG signal that occurred in the drift elimination stage was avoided by adding appropriate A/D and D/A converters and latches. The response of the overall EOG signal acquisition system was found to be remarkably linear and the overall system designed was much cheaper than existing bioamplifiers for the same purpose. The development of this novel EOG biopotential amplifier also helped us in working on some previously unexplored applications in medical instrumentation such as reliable hospital alarm systems. The significant achievement of this bioamplifier is its versatility, for it can used to work on pragmatic biomedical applications of EOG signal processing as well as aid in theoretical analysis experiments.

VI. Conclusion

A novel EOG biopotential amplifier has been designed and tested to satisfy both DC drift elimination and maintenance of signal linearity. This significant circuit is found to be ideal for both theoretical analysis of the EOG signal as well as for practical signal processing applications based on EOG. It is hoped that this work would contribute significantly in aiding to understand the EOG signal and initiate greater research in medical instrumentation design for paralyzed people.

Current EOG Research Work at IIT Guwahati

The success of this novel EOG biopotential amplifier has helped us to understand the EOG signal better and currently we are working on a new mathematical model of the muscles around the eyes as well as some practical EOG signal processing based biomedical applications.

References

[1] S. Venkataramanan, Pranay Prabhat, Shubhodeep Roy Choudhury, Harshal B. Nemade, J.S. Sahambi, "Biomedical Instrumentation based on EOG Signal Processing and Application to a Hospital Alarm System," *Proc. of IEEE ICISIP 2005*, pp. 535-540, Chennai, India.
[2] Nitish V. Thakor, Johns Hopkins School of Medicine, "Biopotentials and Electrophysiology Measurement", *The Measurement, Instrumentation and Sensors Handbook*, Editor - John G. Webster, CRC Press LLC, 2000.
3] J.G. Webster, "Reducing motion artifacts and interference in biopotential recording", *IEEE Trans. Biomed. Eng.*, pp. 31, pp. 823 - 826, 1984.
[4] S. Venkataramanan, Shubhodeep Roy Choudhury, "EOG Biopotential Amplifier Design – Challenges and Advantages", Dept. of ECE, Guides – Dr. Harshal B. Nemade and Dr. J.S. Sahambi, *Thesis – Phase I,* IIT Guwahati, India, pp. 1 -35.
[5] J.H. Nagle, "Biopotential amplifiers", *The Biomedical Engineering Handbook*, Bronzino J.D. (Ed.), Boca Raton (FL), CRC Press, pp. 1185 - 1195, 1995.
[6] Rangaraj M. Rangayyan, *Biomedical Signal Analysis: A Case Study Approach,* John Wiley and Sons Inc., First Edition, 2001.