



Noise immune Bio Potential Amplifier Design for Neural Amplifying Applications

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ABSTRACT: This paper presents the Biopotential amplifier which is able to amplify the weak neural signals sensed at the electrode tissue interface. This amplifier is intended for signal amplification for using with low frequency physiological signals. This bio amplifier was designed in 180nm CMOS process with the power supply of 1.8V which passes signals from 1Hz to 2kHz, which resulted in a high gain of 65dB, high Common Mode Rejection Ratio (CMRR) of 109dB with input referred noise of $2.5\mu\text{Vrms}$ over the range of 100Hz and this design resulted in a power consumption of 0.402mW.

KEYWORDS: Bio potential, CMRR, Input Referred noise.

I. INTRODUCTION

With the rapid development in microelectronics in the recent decades, more applications require an ultra-low amplitude signal measurement module, such as health monitoring devices in biomedical applications. Monitoring different bio signals of the human body is very important since it helps to know vital health information of the human body from the acquired data [1]. These acquired data are used by medical practitioners to diagnose diseases. Biomedical signals, such as electrocardiogram (ECG), Electromyogram (EMG), Electroencephalogram (EEG), more are characterized by their voltage and frequency characteristics. Bio potentials are the result of physiological phenomena and can be measured between electrodes placed on the body of a person. For the sustenance of life in the human body produces a large number of physiological processes that take place continuously [2]. Many of these processes generate bio potentials that could be measured in a non-invasive manner. Because of this, to maintain a high level of signal to noise ratio, the front end signal conditioning circuit with a very low equivalent input noise is desired [3]. The development of amplifiers to record bio electrical activity of nerves and muscles has an important impact on the bio signals as they are minute signals which also require high Gain amplifier with better noise removal features in the front end design. The Bio potential amplifiers possess the following features to set the versatile features such as low power operation, small input referred noise and large CMRR ratio [3]. This Paper proposes a noise immune Bio potential amplifier design which is designed for high Gain and made stable to reject the noisy signals at the output of the amplifier.

II. RELATED WORKS

R. R. Harrison and C. Charles[9] had developed a front end IC design with 16 channel of the Differential amplifiers along with common mode feedback circuitry at the first stage and instrumentation amplifier at the second stage with resistive feedback path. Number of channels have been increased in this method so that they consume more area. This amplifier have a mid-band gain of 46dB. M. Chae, J. Kim, and W. Liu[3] had proposed a self-biased design reducing the need of the common mode feedback circuitry. A fully differential scheme with single ended output sets an advantage in terms of high CMRR Hence the design of the amplifier was always a differential one with single ended output to attain a maximum CMRR ratio was the inference from the above papers. Devarshi Mrinal Das, Abhishek Srivastava, J. Ananthapadmanabhan, Meraj Ahmad, Maryam Shojaei Baghini[1] have proposed NMOS complimentary transistor input pair biased in sub-threshold region to effectively boost the trans conductance of the input pair and reduce the input referred noise.

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III. DESIGN TOPOLOGY OF BIO POTENTIAL AMPLIFIER

CMOS Operational amplifier is a core element for analog signal acquisition circuits. The design is comprises with two stages. To enhance the signal strength of the amplifier various stages has been used to increase the efficiency of the design without large area and power consumption. Figure 1. describes the design stages involved in Biopotential amplifier. The overall performance of the circuit depends on the performance of the input differential stage as they act as the first block of the amplifier design.[4] The differential to single-ended conversion stage follows the differential amplifier and is responsible for producing a single output and also provides the necessary bias for the second gain stage. The compensation circuitry is added to provide the stability of the amplifier[7].

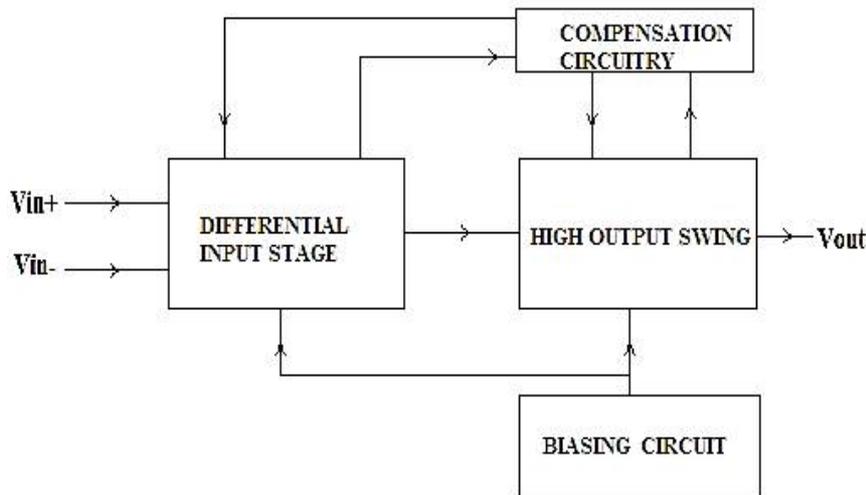


Fig 1. Block Diagram of Bio potential amplifier design

IV. DESIGN OF BIO POTENTIAL AMPLIFIER

The schematic design of the Bio potential amplifier is shown in figure 2. The transistors M1, M2, M3, and M4 form the first stage of the op amp the differential amplifier with differential to single ended transformation. Transistors M1 and M2 are standard N channel transistors which form the basic input stage of the amplifier. The gate of M1 is the inverting input and the gate of M2 is the non-inverting input. A differential input signal applied across the two input terminals will be amplified according to the gain of the differential stage. The current mirror active load used in this circuit has three distinct advantages. First, the use of active load devices creates a large output resistance in a relatively small amount of die area.[5] The current mirror topology performs the differential to single-ended conversion of the input signal, and finally, the load also helps with common mode rejection ratio. In this stage, the conversion from differential to single ended is achieved by using a current mirror M3 and M4. The differential current from M1 and M2 multiplied by the output resistance of the first stage gives the single-ended output voltage, which constitutes the input of the second gain stage.[7] The second stage is a current sink load inverter. The purpose of the second gain stage, as the name implies, is to provide additional gain in the amplifier. Consisting of transistors M6 and M7, this stage takes the output from the drain of M2 and amplifies it through M6 which is in the standard common source configuration. M6 is the driver while M7 acts as the load.

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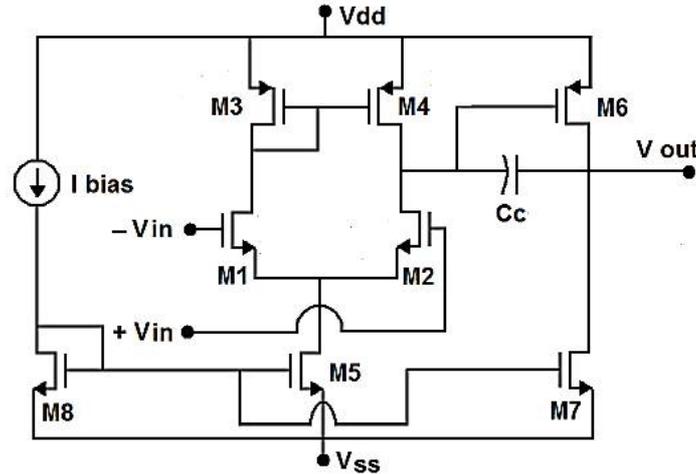


Fig 2. Schematic of the Bio potential amplifier

V. SIMULATION RESULTS OF THE BIO POTENTIAL AMPLIFIER

The Transient analysis for the bio potential amplifier is done by using Cadence Spectre simulator. When applied with the input Sine wave of $\pm 1.5\text{mV}$ at the frequency of 1 kHz, in the design in the figure 3 the output wave obtained is amplified to $\pm 1.5\text{V}$.

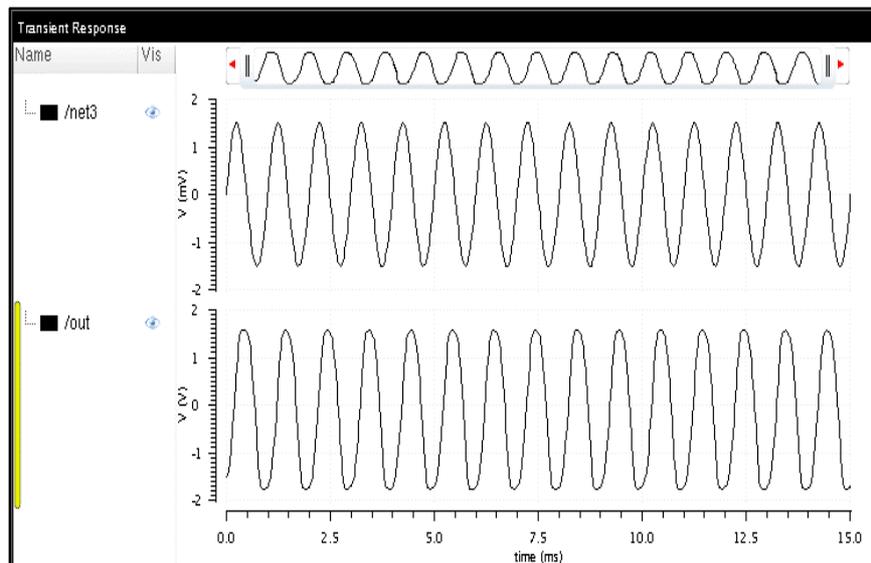


Fig 3. Transient response of the amplifier

The frequency response curve for the bio potential amplifier is shown in the Figure 4. The gain margin, gain bandwidth, and phase margin were obtained by using ac frequency sweep analysis. The voltage gain is 64.79dB at 1.05Hz where the gain starts to cut off around 758.57Hz (the -3dB frequency). The gain bandwidth is 1.098MHz (the unity gain frequency, 0dB).

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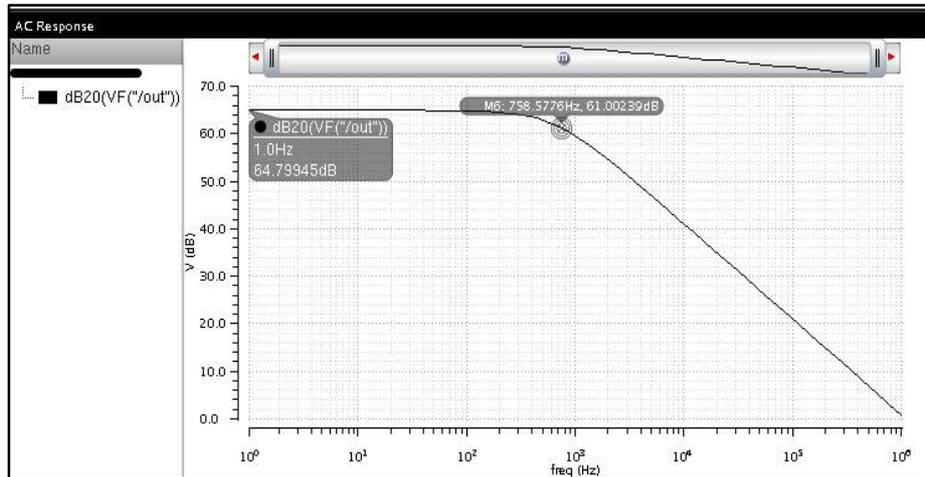


Fig 4. Gain Response of the amplifier.

V. NOISE ANALYSIS

a) External Noise Sources

Amplitude of the bio signals are very small in the range of few hundreds of μV to a few mV. As the amplitudes are very small these signals may get corrupted by some inherent noise factors in the front end of the circuit design. Noise is a purely random signal, cannot be predicted at any time. Instantaneous noise voltage amplitudes are as likely to be more negative. When plotted, they form a random pattern centered on zero. Since noise sources have amplitudes that vary randomly with time, they can only be specified by a probability. The probability that a noise amplitude will be higher or lower than the mean falls off in a bell shaped curve, which is symmetrical around the center. Considering a noise model as the noise source which is applied to a noiseless amplifier design the spike waves are produced as the resultant of the noise model insertion. Fig 5. Describes the Noise model insertion in the amplifier.

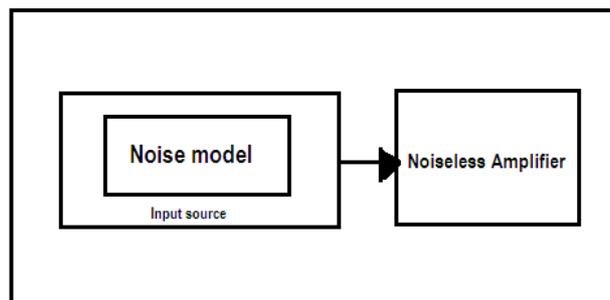


Fig 5. Amplifier design with noise model

b) Internal Noise sources

All op amps have parasitic internal noise sources. Noise is measured at the output of an op amp, and referenced back to the input. Therefore, it is referred as called equivalent input noise.

$$V_n^2 = \frac{V_{on}^2}{A} \dots (1)$$

Where, V_n^2 – Total output Noise in the circuit; A - Gain of the amplifier.

The output referred noise can be analysed from the frequency domain analysis for obtaining the power spectral densities. To input refer the total output noise divided by gain from the desired signal to the output as in equation 1.

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The designed Bio amplifier contributes to a total input referred noise of 1.38 μVrms at 10Hz. Figure 7. indicates the input referred noise of the amplifier in spectre analysis.

c) Noise Efficiency Factor

Due to small frequency bandwidth of the bio potential signals, it is the target noise level that defines the power dissipation of the bio potential amplifiers. As the type and the number of noise sources increases, the total noise contribution in the circuit also increases. Hence the amplifier requires more power to achieve the target noise range. NEF is the factor introduced to compare the power and noise performance of the amplifier design [3].

$$NEF = \sqrt{\frac{2I_{total}}{\pi V_t 4kTBW}} \dots (2)$$

Where, BW is the Bandwidth, I_{total} is the total current, V_t Thermal noise voltage, T-Temperature.

VI. SIMULATION RESULTS OF NOISE ANALYSIS

Most electronic systems include noise contributions from several devices. To correctly calculate the noise we need to account for both the system's deterministic electrical behaviour and its noise contribution. Any noisy device can be represented as a noiseless version of itself properly connected to suitable noise voltage and current sources. Insertion of noise leads to noise spikes in the output of the circuit as shown in the figure 6.

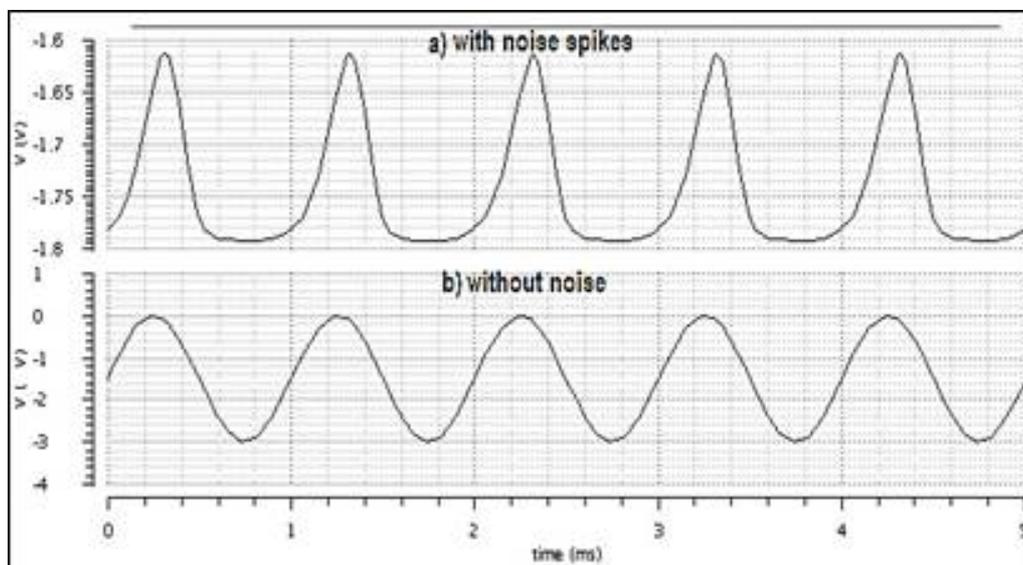


Fig 6. Resultant waveforms with and without noise in amplifier

Circuit noise is specified as an input referred RMS spectral noise density per root unit bandwidth where the total output noise is the input referred noise spectral density multiplied by the circuit gain and the square root of the noise bandwidth. Figure 7 Input referred noise of the amplifier measured in the frequency domain analysis [12].

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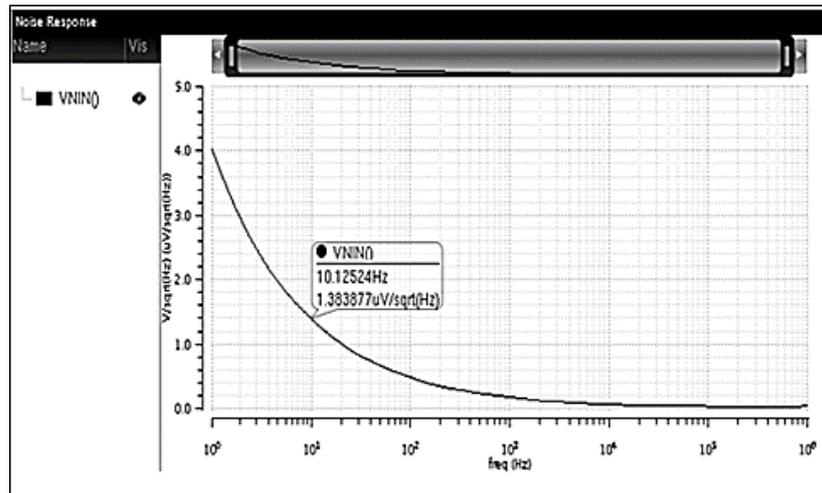


Fig 7. Input referred noise of the amplifier.

VII.PERFORMANCE EVALUATION

Table 1.Simulation results and specifications of the design of Bio potential amplifier

| <i>Parameters</i> | <i>Specifications</i> | <i>Simulation Result</i> |
|----------------------|-----------------------|--------------------------|
| Supply voltage | 1.8V | 1.8V |
| Input signal | NA | 1.5mV |
| Gain | >60dB | 64.79dB |
| f(-3dB) | NA | 758.57Hz |
| GBW | NA | 1.098MHz |
| Phase margin | >60deg | 61deg |
| CMRR | >100dB | 110dB |
| Input Referred Noise | NA | 1.38 μ V/Sqrt(Hz) |
| Power Dissipation | <0.5mW | 0.402mW |
| NEF | <6 | 2.3 |

VIII.CONCLUSION

The proposed Bio amplifier design is capable of amplifying the weak signals with low frequencies. This amplifier design has yielded high gain output with high CMRR ratio and low power consumption. The designed bio potential amplifier design is able to reject the noise signal appearing at the electrodes.This design also contributed to the low noise characteristics which is an important feature for bio potential applications.

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