Design of Low Power Neuro-amplifier Circuit with Miller Compensation Technique for Biomedical Neuro-implantable Devices

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Abstract

Neuro-amplifiers form an integral part of biomedical implantable devices. In this paper, we design a neuro-amplifier circuit with Miller compensation capacitor. The neuro-amplifier design is based on operational transconductance amplifier (OTA) with an active load. In this work, performance of the neuro-amplifier is enhanced by incorporating the Miller compensation technique. Design and simulation of the neuro-amplifier circuit is performed using SPICE simulation software. Body biasing and feedback techniques are imparted to optimize the circuit performance. Simulation results show that the neuro-amplifier circuit has a mid-frequency gain and 3-dB bandwidth of 48dB, and 16kHzrespectively.

Keywords: Neuro-implantable device, neuro-amplifier, operational transconductance amplifier (OTA), bio-medical, Miller compensation.

1 Introduction

In recent times, much focus has been on developing implantable biomedical devices for health-care applications [1-2]. A typical biomedical device constitutes sensor modules like chemical/biological sensors [3-11], thermal sensors [12], pressure sensors [13-14], signal processing units like wireless power units [15-16], rectifier [17-18], amplifier [19-20], regulator [21], etc., to mention a few. Typically, the sensor and actuator modules are realized with micro-electro-mechanical systems (MEMS) technology. On the other hand, the signal processing elements are realized with conventional CMOS integrated circuit (IC) technology. Amongst various applications, development of neuro-implants for brain computer interfacing (BCI) is a challenging task especially due to its stringent performance metrics. Biomedical devices for monitoring neural activities have been the focus of research mainly for addressing issues related to neural disorders [22-23]. There are various sub-units that constitute a biomedical device for detecting neural signals. Neural activities are monitored with MEMS based multi-electrode arrays [24].Apart from neural stimulation [22-25], the other applications include recording and amplification of the analog neural signals using a neuro-amplifier [26-27]. The neural amplifier amplifies the action potential (AP) and local field potentials (LPF). Wireless modules are also typically integrated not only for wireless power transfer but also for signal transmission. Power supply transferred wirelessly is processed with power rectifier and AC-DC converter circuits. This regulated DC supply is used by other circuits in the IC. Wireless power transfer technique typically realized by using inductive coupled links has advantages such as effective silicon estate utilization due to elimination of on-chip battery, high efficiency, improved device life time, to mention a few.

Design of the aforementioned building blocks is challenging, especially due to the stringent power budget in an IC and its trade-off with various performance metrics. In this paper, we investigate the design of a neuro-amplifier-a operational transconductance amplifier (OTA). Design and implementation of the circuits is performed using SPICE software.

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2 Architecture and circuit topologies

The general architecture of a bio-implantable device is shown in Fig 1. Various modules in a bio-implantable device include the following: (i) wireless power transfer module, (ii) power rectifier, (iii) neuro-amplifier, (iv) neural simulator and (v) signal processing and communication module.

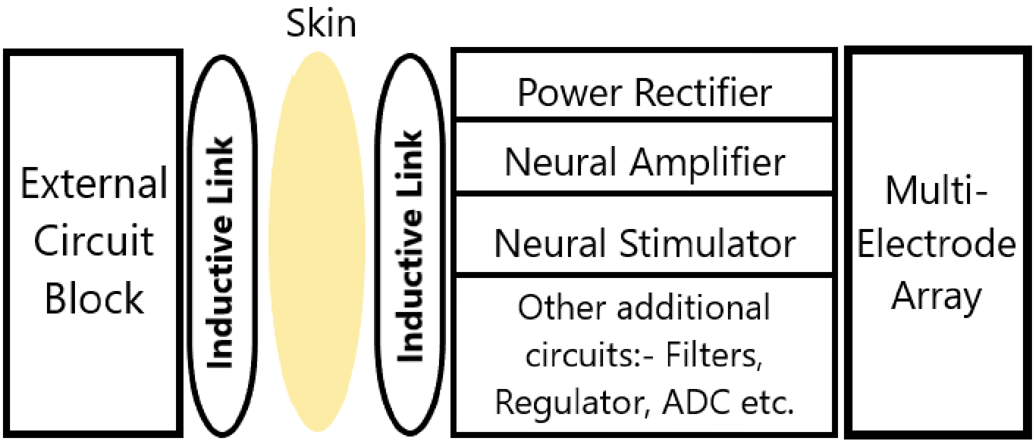


Fig. 1. Block diagram of a general implantable device and its components.

Typically, a bio-implantable device gauges neural activity with micro-electrode sensor arrays followed by amplification of neural signals using a neuro-amplifier. Subsequently, neuro-amplifier output undergoes digital signal processing so that it could be transmitted to the external block unit. The wireless power transfer is converted into a DC signal with a power rectifier circuit.

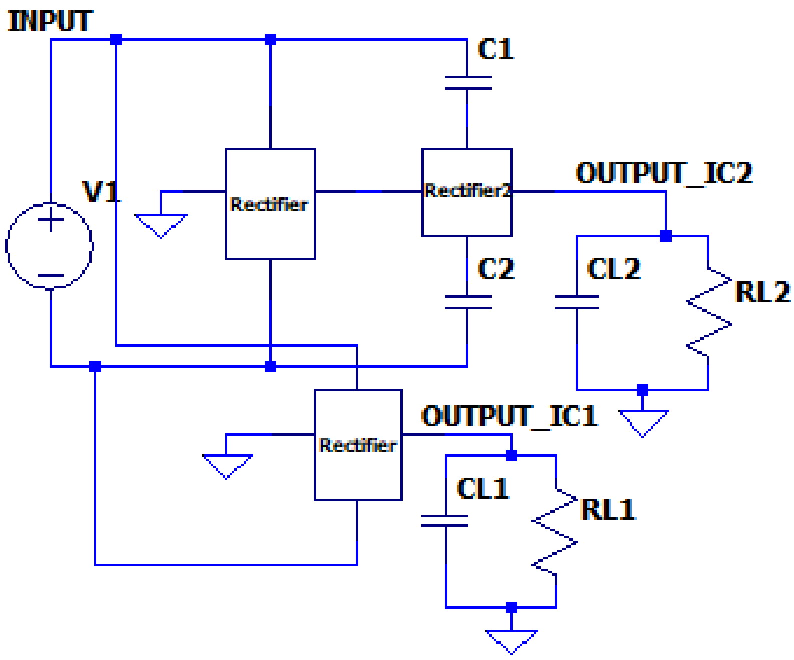
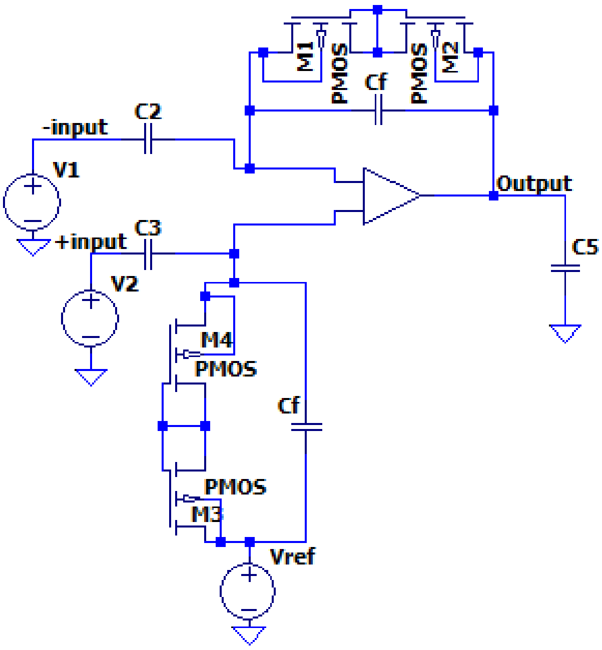


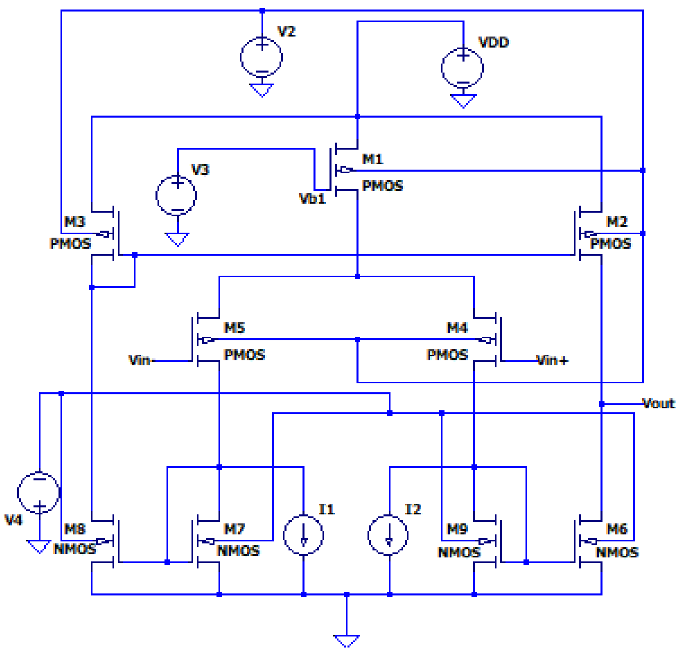
Fig. 2. Typical schematic of an implantable device for neural recording [18]

An implantable device for neural recording contains two integrated circuits (IC's) as shown in Fig. 2[18]: (i) IC1:- It encompasses sensor arrays which gauges neuro-signals and feeds to the neuro-amplifier. The neuro-amplifier amplifies the neuro signal and passes it to subsequent signal processing elements for transmission, and (ii) IC2:- This IC transmits the processed signals. Further, it delivers wirelessly transmitted AC power using the power rectifier (AC-DC converter).

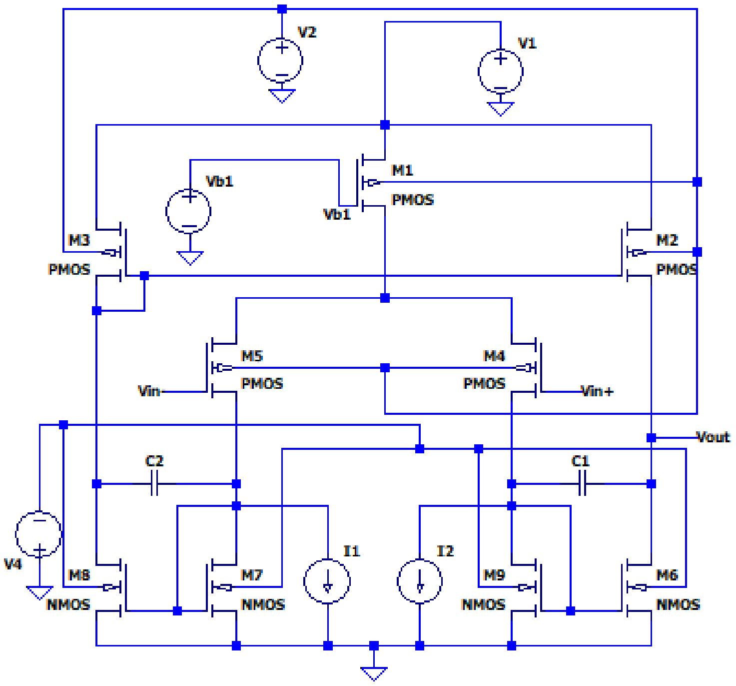
The neuro-amplifier is used for amplification of signals indicating neural activity i.e. action potential and LPF. Gain of the amplifier is determined by the ratio of input capacitance with the feedback capacitance, whereas the bandwidth is controlled by the feedback circuit. The given neuro-amplifier uses current mirror circuitry to increase output resistance for a high open loop gain as shown in Figure 3(a). The operational transconductance amplifier (OTA)with active load (current mirror circuit) takes the input signal as differential input and amplifies the differential signal (Figure 3(b)).OTA is a voltage controlled current source that is used to give high output impedance resulting in a high open loop gain. In order to reduce flicker noise, the gate area of input differential pair can be increased and biased in weak inversion to maximize the gm/ID ratio [25].To minimize the thermal noise effects the rest of the transistors are biased in strong inversion mode.



(a)



(b)



(c)

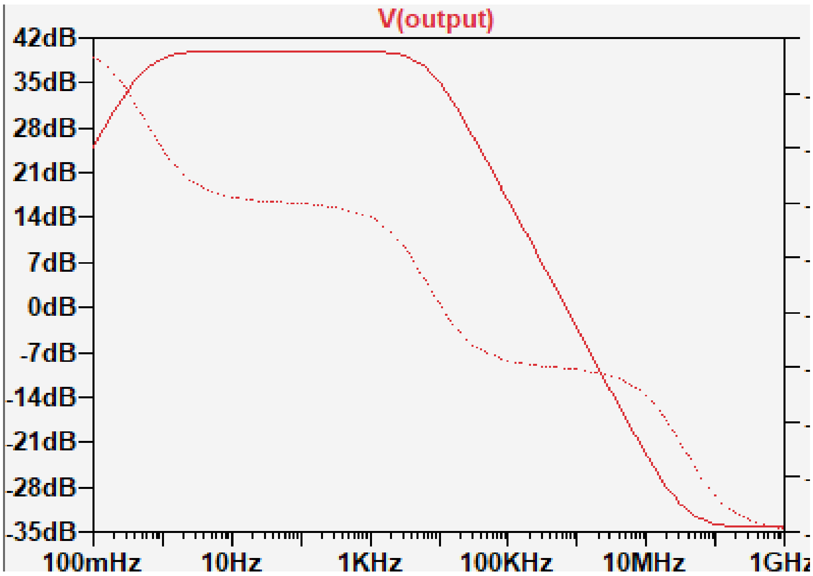
Fig. 3. Schematic of (a) neuro-amplifier, (b) OTA circuit, and (c) OTA circuit with Miller compensation capacitor

The OTA circuit with Miller compensation capacitors (C1 and C2)is shown in figure 3(c).Here, the capacitors C1 and C2 are connected to the drain of the current mirror MOSFET's (M6-M9).

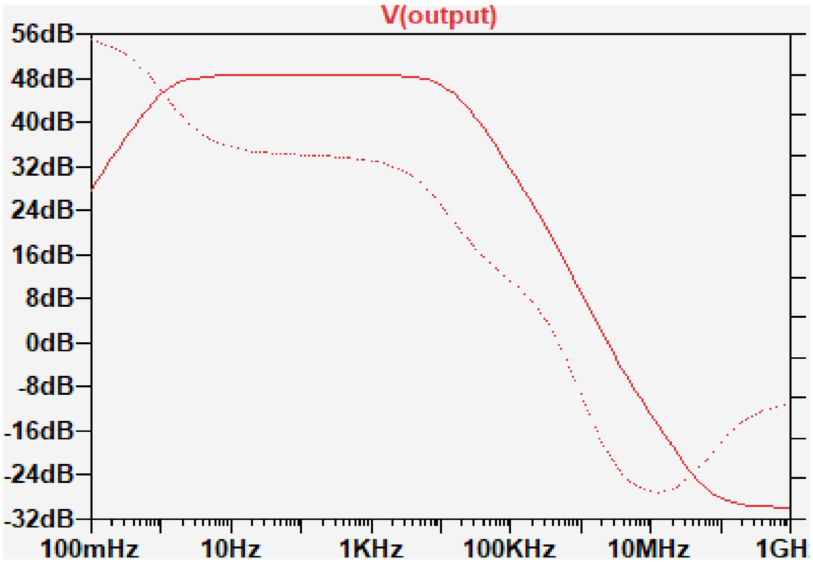
3 Results and Discussion

In this section, we perform the design-optimization of the neuro-amplifier circuits shown in Figure3 using simulation software. The neuro-amplifier circuit (Figure 3) constitutes of the OTA that is designed for the required specification of neuro-amplifier circuit. OTA circuits are biased with a supply voltage of 0.8V.

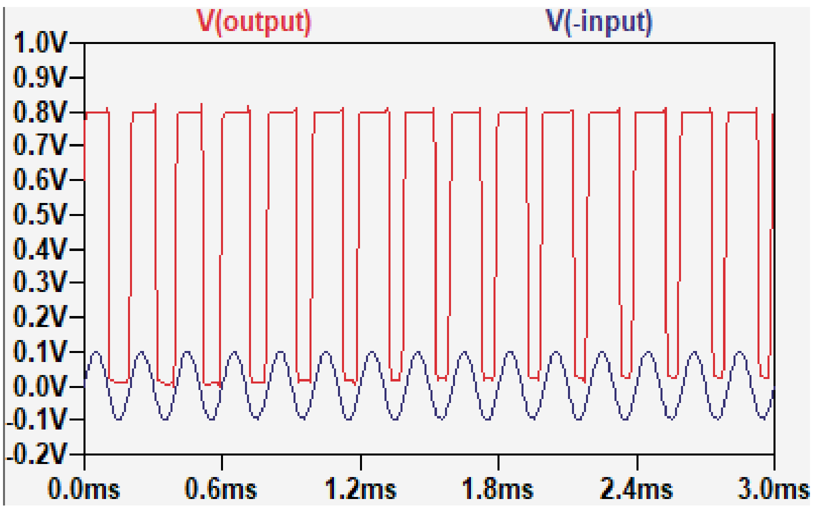
DC-operating points are fixed considering interplay between various performance metrics. The neuro-amplifier is optimized for high gain-bandwidth product by careful design of transistor aspect ratio, biasing voltages and bias currents. From the frequency response plots shown in figure 4(a) and 4(b), it is observed that the neuro-amplifier circuit with Miller compensation capacitors has a higher mid-frequency gain of 48dB as compared to the original gain of 40dB. The 3-dB bandwidth of the neuro-amplifier with Miller capacitors has also improved to 16 kHz from 5 kHz. These Miller capacitors have a significant impact on the bandwidth and stability of the circuit. It is observed that with Miller compensation technique there is an increase in the bandwidth and stability of the amplifier. A comparison of present work with the reported works in treatise is summarized in Table I. The values of mid-frequency gain and 3-dB bandwidth obtained in this work are suitable for AP and LPF signal amplification. The designed amplifier depicts a mid-frequency gain of 48dB, and the 3-dB bandwidth is approximately 16 kHz.



(a)



(b)



(c)

Fig.4. Neuro-amplifier circuit (a) frequency response of original circuit[25], (b) frequency response of the circuit with Miller compensation, and (c) transient response of the OTA.

Table 1: Comparison of the Simulated Neuro Amplifier with the Previous Works

Parameters	Ref [28]	Ref [29]	Ref [30]	Ref [26]	Ref [31]	Ref [32]	Ref [25]	This work*
Technology	1.5 µm	0.180 µm	0.35 µm	0.180 µm	0.5 µm	0.5 µm	0.180µm	0.180µm
Supply voltage	3V	1.8 V	3.3V	1.2 V	3 V	2.8 V	0.8V	0.8 V
Power dissipation	115 µW	6.25 µW	23.4 µW	N/A	4.04 µW	7.56 µW	0.8 µW	0.35 µW
Gain	39.3 dB	45.38 dB	73.9 dB	39.2 dB	62 dB	40.9 dB	39 dB	48 dB
Low frequency	0 Hz	5.02 Hz	1 Hz	0.25 Hz	N/A	N/A	1 Hz	1 Hz
High frequency	9.1 kHz	2.927 kHz	10 kHz	28 kHz	4 MHz	N/A	5 kHz	16 kHz
Input referred noise	7.8 µV	1.53 µV/sqrt (Hz)	1.3 µV	5.79 µVrms	59 nVrms/sqrt (Hz)	1.66 µVrms	0.8 µVrms	N/A

4 Conclusion

This paper elucidates the design and implementation of aneuro-amplifier CMOS OTA circuit using SPICE software. The neuro-amplifier circuit was optimized for gain and bandwidth. Results show that the neuro-amplifier circuit depicts a mid-frequency gain of 48dB, and 3-dB bandwidth of approximately 16 kHz. Circuit optimization and body biasing techniques were implemented to enhance circuit performance metrics.

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