An Innovative Approach of Implementation of High Performance Low Voltage Amplifier for Biomedical Applications

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Abstract:
In this paper, a high performance current-mode instrumentation amplifier has been proposed for low noise, low power, high CMRR and adjustable gain with an external resistor for various biomedical signal processing. The portable biomedical instrumentation has become an important part of diagnostic and treatment instrumentation, including telemedicine applications. The low voltage and low-power design tendencies are becoming more prevailing one. A two-electrode bio potential amplifier design is discussed with a high common-mode rejection ratio (CMRR), high input voltage tolerance and standard first-order high-pass characteristic. The circuit makes use of passive components of popular values and tolerances. The modern battery cell voltages are in the range of 3–3.6V that require appropriate circuit solutions powered by a single 3V source. This innovative amplifier tolerates a 1V common mode voltage with 50 mA common mode current and 2 V input DC voltage which in turn provides a CMRR of 60 dB. The low voltage amplifier has got the applications in various systems say Holter-type monitors, defibrillators, ECG monitors, biotelemetry devices etc. This low voltage current-mode amplifier is designed using 0.18μn CMOS technology for the various biomedical applications. The amplifier circuit is based on the use of two positive current conveyors of second generation and a current differential output stage. The device exhibits high common-mode rejection ratio which is gain unaffected in a wide frequency band. SPICE simulation results are promising for high frequency medical applications.

Keywords: *Instrumentation amplifier, high CMRR, low power, biomedical signal, component ECG amplifier, Bio-potential amplifier, Low supply voltage amplifier, AC coupled amplifier, low-voltage, High CMRR.*

I. INTRODUCTION

The recording biomedical signal is one of the challenges in a biomedical electronics detection system, because biomedical signals have very weak amplitude and low frequency, usually of few milli-volts or less and the frequency below 1 KHz [1]. The biomedical electronics detecting system is shown in Fig. 1, which consists of electrodes, amplifier, LPF, Sample and Hold (S/H) and ADC. Biomedical signals, such as EEG/ECG signals, are characterized by their low voltage-levels and very low frequencies. Thus, an instrumentation amplifier (IA) must exhibit very low input-referred noise [1-12].

These biomedical signals are acquired and transferred to the voltage type signals with amplitude of several milli-volts. The used IA must have high input impedance, low output impedance, limited bandwidth, and low power consumption [1-6]. Additionally, it must have adequate gain, high power-supply rejection ratio (PSRR) and high common-mode rejection ratio (CMRR) to suppress noise.

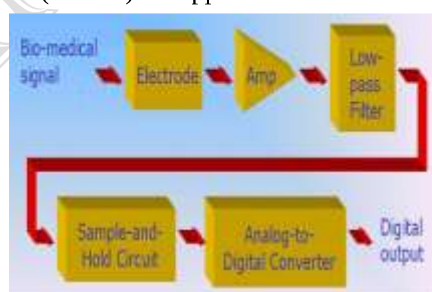


Figure 1 Block Diagram of Biomedical Application [1, 5]

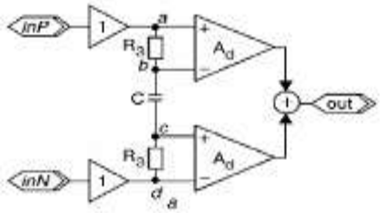
There are lot many application areas, especially in biomedical instrumentation, that require wide bandwidth (BW) low voltage amplifiers with high common mode rejection ratios (CMRR), [7-8]. It is well known that the conventional based on the operational amplifier topologies exhibit a narrow BW which is dependent on the gain. On the other hand these topologies require precise resistor matching so as to achieve high CMRR [9-10]. The Current mode instrumentation amplifiers have better performance with respect to CMRR and frequency range of operation and also they do not require resistor matching [11].

II. BASIC CONVENTIONAL CONFIGURATIONS OF AMPLIFIERS

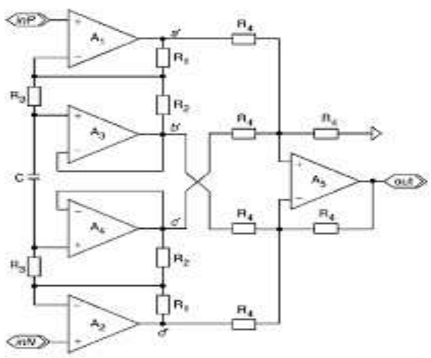
In addition to the well-known (ECG) and blood pressure signals, various telemedicine applications require instruments of improved design, compatible with modern microcomputers and microcontrollers.

The low voltage and low power are among the most important requirements for such instrumentation. Now a day, the rechargeable or non-rechargeable 3.6V/3V battery voltages need adequate bio-potential amplifiers. The high performance of the amplifier should be obtained in spite of the low supply voltage limitation, especially concerning electrode polarization voltage and common-mode input voltage tolerance [10-15].

The most widely used circuits for bio signal amplifiers are based on the three-operational-amplifier configuration, or instrumentation amplifier, followed by an additional AC-coupled stage. Usually, the 'classical' amplifier gain is split between the instrumentation amplifier and the stage after the high-pass decoupling filter. The first stage gain is set to low values, because of the electrode polarization potentials. Their voltage difference can reach up to about 200mV, depending on various factors (electrode metal, conductive gel, patient skin etc.), and appears as an input signal DC component.



(a)



(b)

Figure 2 Basic amplifier circuit (a) Simplified & (b) Detailed Circuits [2, 6]

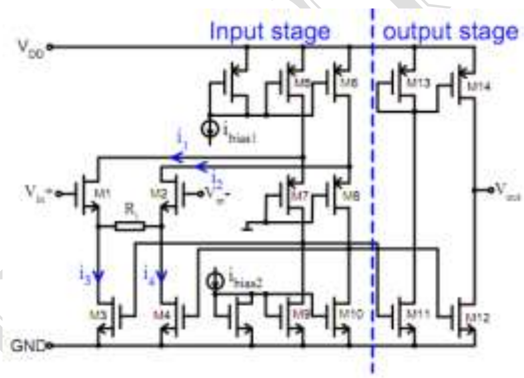
$$V_{out} = A_d (V_a - V_b + V_c - V_d) \tag{1}$$

$$V_{out} = \mathrm{A_d} \times \left[\frac{s2R_3C}{1+s2R_3C}\right] \times \left(V_{IN}P - V_{IN}N\right) \tag{2}$$

where b, c and d are the inputs to the differential amplifiers and A_d is the gain of the amplifier. And the high pass cut-off frequency is defined by the time constant $2R_3C$ that also constitutes the first order low pass filter [16-20]. The differential gain of the amplifier is given as:

$$A_d = 1 + \frac{R_1}{(R_2 \parallel R_3)}, with R_3 \gg R_2 we get$$
$$A_d = 1 + \frac{R_1}{R_2} \tag{3}$$

The minimum expression for a conventional amplifier can be calculated as:



$$CMRR = \left(\frac{A_d 1\_4}{A_{cm} 1\_4}\right) \times \left(\frac{A_d 5}{A_{cm} 5}\right)$$
$$CMRR = \left(\frac{A_d}{1}\right) \times \left(\frac{4\delta}{1 + \frac{R_4}{2R_4}}\right) \tag{4}$$
$$CMRR = A_d \times \frac{1.5}{4\delta}$$

where δ is the tolerance of the resistor R_4 used in the circuit.

Figure 3 Conventional amplifiers [8, 11]

In order to reduce the noise of the amplifier, there are two different design methods that have been implemented so as to improve the prior limitations i.e. particularly flicker noise which is less effected with the use of PMOS and then we can have the combination of PNP transistor using BJT since it has got better noise characteristics. The commonly used standard amplifiers are unable to work at low supply voltages such as below 1V [21-25].

Moreover, there exists a limitation for analog circuits to properly operate at low-voltage supplies is due to the limitation of the threshold voltages [26-28]. The first stage amplifier consists of M1~M10 and the input resistor R_i, which form a feedback loop. By KCL, the difference current between i_4 and i_3 is equal to 2Vin/Ri [29-35]. Therefore, this circuit is used as a transconductance (g_m) cell whose overall G_m is equal to 2/Ri. By the second stage amplifier, the g_m cell output is then converted to a single-ended output.

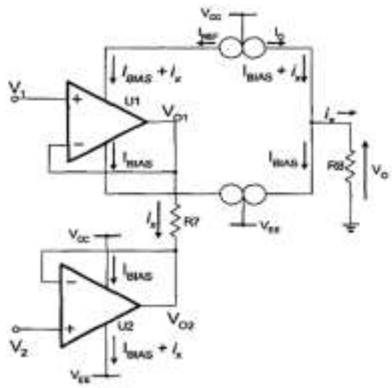


Figure 4 Configuration of Basic CMIA [15]

The current-mode instrumentation amplifier (CMIA) is an another approach that does not require resistor matching to achieve a good CMRR [36-42]. This design approach is more commonly suited to a VLSI design approach, leading to the applications in implantable biomedical devices.

This current-mode approach was discussed and fabricated using discrete devices that resulted in the desired CMRR of approximately 80dB. A circuit approach limited by the matching of the open-loop gains of the op-amps employed in the design for a CMIA, which is then fabricated in a 0.18µn CMOS technology, using the current mirrors as current summing networks. The current mirroring technique employed in a CMIA has two main advantages over the standard approach i.e.

- The first is that no resistor matching is required to achieve a high CMRR.
- The second advantage is that a CMIA does not require "ideal" op-amps.

The basic design of a CMIA, presented in Figure 4, consists of two distinct stages; a differential input stage, and a gain stage. The input stage consists of two identical op-amps connected as unity-gain buffers. The outputs of these op-amps are connected via resistor R_7. Any differential signal (V_a) applied to the input of the CMIA will induce a current, to flow through R_7. In order to achieve differential gain, the current (i), is mirrored i.e. copied into R_8 [43-45]. The differential gain of the CMIA is simply the ratio of R_8/R_7.

$$V_{O1} = \left(\frac{V_d}{2+V_{cm}}\right)\frac{A_{OL1}}{1+A_{OL1}} \tag{5}$$

$$V_{O2} = \left(\frac{-V_d}{2+V_{cm}}\right)\frac{A_{OL2}}{1+A_{OL2}} \tag{6}$$

If, the two gains are assumed to be equal i.e. $A_{OL1} = A_{OL2}$ then

$$i_x = \frac{V_d}{R_7} \tag{7}$$

If the open loop-gains of the input op-amps are different, a finite CMRR will result [36]. The magnitude can be approximated by

$$CMRR = \frac{A_D}{A_{CM}} = \frac{A_{OL1} * A_{OL2}}{A_{OL1} - A_{OL2}} \tag{8}$$

III. PROPOSED APPROACH OF THE LOW VOLTAGE AMPLIFIER

The biomedical signals, such as EEG/ECG/EMG etc signals, are characterized by their low voltage-levels and very low frequencies. Thus, a low voltage and highly precise instrumentation amplifier (IA) is required so as to ensure the suitable and true measurement of the value of the most important signals, which also be able to exhibit very low input-referred noise [47].

These biomedical signals are acquired and transferred to the voltage type signals with amplitude of several milli-volts. Thus, the desired IA must have high input impedance, low output impedance, limited bandwidth, and low power consumption [48]. Additionally, it should also have adequate gain, high power-supply rejection ratio (PSRR) and high common-mode rejection ratio (CMRR) to suppress noise.

In order to eliminate and optimized the presence of the flickering noise at the output of the amplifier, this circuit has been designed and simulated with the use of 0.18µn CMOS technology that is well efficient to eliminate this presence of noise.

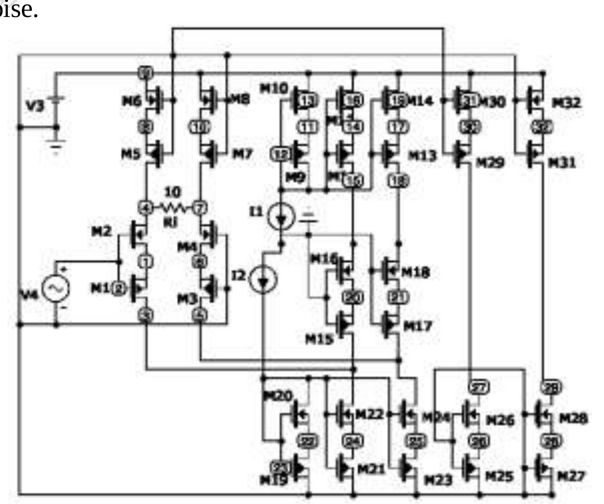


Figure 5 Proposed Low Voltage & High Performance Amplifier using CMOS technology

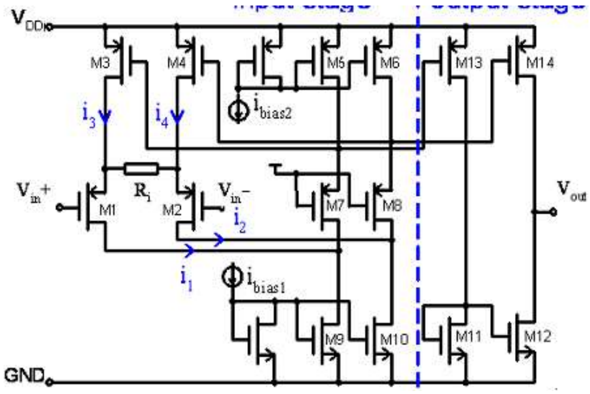
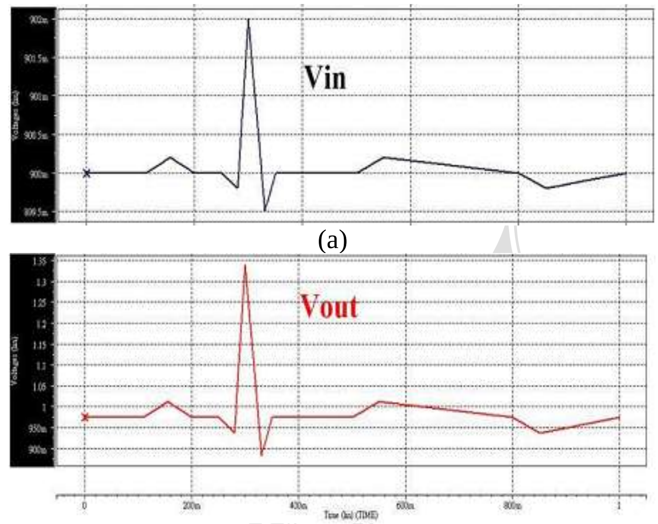


Figure 6 Low Voltage & High Performance Amplifier using PMOS technology



(a)

(b)

Figure 7 Simulation results of the original 2-mV ECG (V_{in}) and the amplified ECG (V_{out}) Signals

The current mirroring technique i.e. copying of the current used in the amplifier has two main advantages over the standard designed approach used. The main advantage is that there is no requirement of any resistor matching so as to achieve a high CMRR value. In this proposed circuit, the transistor (CMOS) from M1 to M24 acts as the input stage of the amplifier whereas, the transistors (CMOS) M25 to M32 constitutes the output stage of the amplifier [49-53].

The resistance connected between the transistors M2 and M4 acts as the feedback loop so as to provide a path to the flow of currents i_2 and i_4. Then, with the help of the KCL the difference between the currents i_2 and i_4 is determined which comes out to be $2V_{in}/R_i$. Now in order to achieve a higher CMRR value for the amplifier, either a very high open-loop gains must be achieved, or the open-loop gains of the amplifier must be tightly matched. Since the extremely high open-loop gains in case of the transistors are difficult to achieve by using low-voltage CMOS processes, the open-loop gains must be tightly matched.

IV. SIMULATION RESULTS AND DISCUSSIONS

In this discussion, a low voltage and high performance amplifier has been proposed for both low power and adjustable gain for various biomedical signal processing with an external resistor using a standard 0.18-µn CMOS technology.

The table 1 shows the simulation results of the proposed low voltage amplifier designed with the help of CMOS transistor input and PMOS transistor input. Besides, the comparison results of the proposed amplifiers with the low noise, low power [11], they reflects both the original signals i.e. a biomedical signal that could be a ECG/EEG/EMG (V_{in}) and the amplified output (V_{out}) signals with the external resistor set to 10 KΩ, as shown in figure 7 (a & b).

The above figures 5 & 6 shows the most suitable and innovative schematic circuits of the low voltage and high performance amplifier using CMOS and PMOS technology, which are the best suitable and can be most commonly used in the various biomedical applications. The proposed circuit has been simulated for level 3 parameters with 0.18µn CMOS technology using pSPICE software.

The above figure 7 (a & b) shows the performance of the proposed amplifier circuit with the input and output performance of the biomedical signal that shows the output signal has been optimized and minimized for the presence of the unwanted flickering noise signal i.e. distortion in the output signal.

Hence based on performance and the simulations of the innovative circuit of the low voltage amplifier, the proposed amplifier achieves the various desired parameters as shown in the below given table 1, say an overall gain of 85.1 dB (CMOS), 92.0 dB (PMOS), etc..

TT, 25°C	**Proposed CMOS Transistors**	**Proposed PMOS Transistors**	**[09]**
VDD (V)	1.5	1.5	0.9
Power (µW)	60.5	62.6	2.2
Ad (db)	85.1	92.0	40.3
Acm (db)	-40.1	-29.3	-19 ~ -22

CMRR (db)	127.3	122	62 – 65
PSRR+ (db)	127.3	121	64 – 68
PSRR- (db)	128	155	62 – 68
Input referred noise (1KHz)	108.7 nV/√Hz	53.9 nV/√Hz	2.6 nV/√Hz
Output noise (IKHz)	3.06 nV/√Hz	5.3 nV/√Hz	Desired

Table 1: Comparative analysis results of the proposed Low Voltage Amplifier between CMOS and PMOS devices

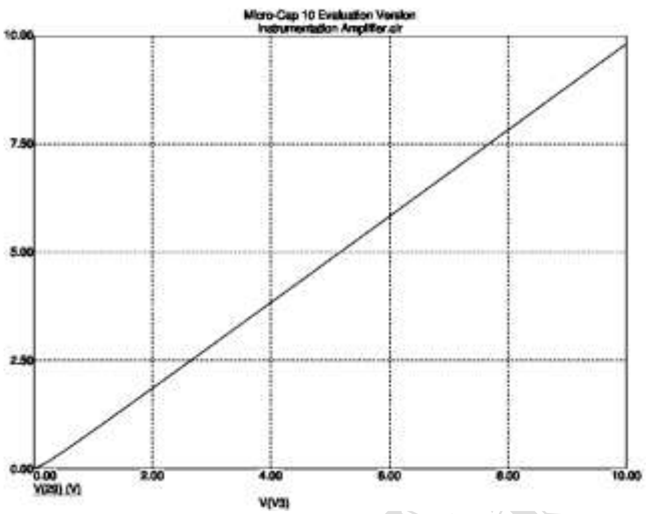


Figure 8 DC analysis of the Low Voltage Amplifier

The above figure 8 shows the DC performance analysis of the proposed circuit reflecting that the amplifier is very much optimized so as to provide the same signal at the output with minimum possible distortion and delay caused due to the presence of the various transistors.

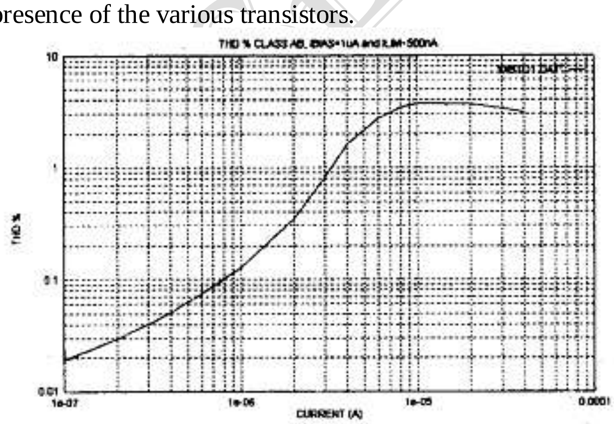


Figure 9 THD analysis of the Low Voltage Amplifier

The above figure 9 shows the threshold distortion analysis of the amplifier that reflects that the distortion behavior of a the circuit in terms of the continuous – time domain, with equal transistors modeled parameters, say the size and W/L ratio.

V. CONCLUSION

Biomedical signals, such as EEG/ECG/EMG signals, are characterized by their low voltage-levels and very low frequencies. Thus, there exists a requirement for a low voltage and high performance instrumentation amplifier (IA). The biomedical signals are acquired and transferred to the voltage signals with amplitude of several milli-volts. Therefore, the IA must have high input impedance, low output impedance, limited bandwidth, adjustable gain and low power consumption. Additionally, it must have adequate gain, high power-supply rejection ratio (PSRR) and high common-mode rejection ratio (CMRR) to suppress noise. This proposed amplifier inherits all the valuable features of the amplifier desired i.e., gain independent bandwidth with no resistor matching requirement. In addition to this, with the use of the differential stage at the input end of the circuit further improves the bandwidth and the level of CMRR.

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