CMOS TRANS CONDUCTANCE BASED INSTRUMENTATION AMPLIFIER FOR VARIOUS BIOMEDICAL SIGNAL ANALYSIS

Mr. Milind Gajare[1], Dr. D. K. Shedge[2]

[1]Research Scholar, Department of Electronics & Telecommunication, AISSMS IOIT Pune, INDIA, milind.gajare@aissmsioit.org

[2] Department of Electronics & Telecommunication, AISSMS IOIT Pune, INDIA dnyandeo.shedge@aissmsioit.org

ABSTRACT

The Trans-conductance operational amplifier's operating frequencies are removed using feed forward design approaches. Amplifiers with enormous Trans-conductance that operate in the Giga hertz frequency range are now available to design. Several trans-conductance amplifiers are employed in the design of medical and industrial applications to aid in the processing of biomedical signals such as electrocardiographs, electroencephalographs, and electromyograms, among others. The proposed study demonstrates the design of an instrumentation amplifier based on CMOS and the processing of biomedical ECG, EEG, and EMG signals using Trans-conductance operational amplifiers. The CMOS manufacturing technique allows sophisticated circuits to be integrated on a small surface area. Noise reduction, low DC offset, high output impedance, and Common Mode rejection Ratio values are all aspects of the Trans-conductance instrumentation operational amplifiers. Electronic Design and Automation tool with 0.13m CMOS process technology was used for circuit implementation and simulations.

Keywords : Trans-conductance; Instrumentation Amplifier; CMOS Process; Biomedical Signals; Bio-potential Signal; CMRR; Frequency response; Signal Measurement

I. Introduction

A high performance CMOS instrumentation amplifier design becomes a popular choice for biomedical circuit design as such designs offers low voltage, low power operating parameters and minimal chip area for component integration. [1-3], [5-6], [9] Biomedical signals also known as bio-potentials [7]. These electrical impulses have a low frequency and a low amplitude. As a result, some type of amplifier circuit is required to accomplish the amplification process for these weak electrical bio potentials. The bio potential amplifier is the amplifier used in the bio potential amplification process. [7-8], [9], [17].

There are numerous types of bio potential amplifiers, such as differential, isolation, operational, and chopper amplifiers [8]. These amplifiers are designed to work with low-frequency and low-voltage biopotentials. Amplifiers must have a high input impedance value, among other requirements. The input impedance of these amplifiers must be at least 100MΩ. Because bio potentials have lower frequencies and only range from Hz to kHz, these biopotential amplifiers should be able to work in the low-frequency range. These amplifiers should be designed with

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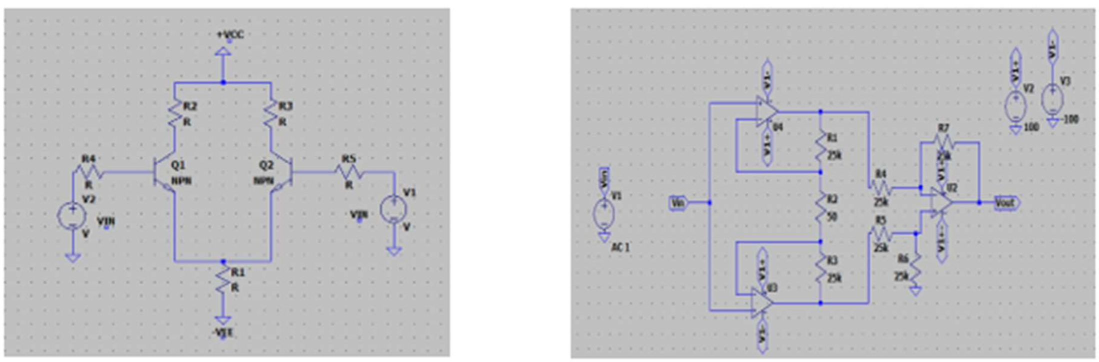
suitable protection and isolation subcircuits to avoid any artifacts and mismatch, and they should give large gain values so that the weak amplitude biopotentials may be easily visible on display devices.

Circuits using differential amplifiers and operational amplifiers are chosen over alternative bio potential amplifiers in bio medical circuit design. Differential amplifiers can filter out interference or common mode signals from electrodes attached to the human body that are used to capture heart movements. As a result, differential amplifiers have a high CMRR value. Differential amplifier also provides good stability [7-8]. Though such amplifier circuit has better ability for interference rejection but it lacks having enough input impedance. To overcome the limitation of the value of input impedance and to achieve large CMRR value operational amplifier based instrumentation amplifier is used in bio potential amplifier circuit implementation.



(a) (b)

Figure 1 (a) Differential Amplifier schematic (b) Instrumentation Op-Amp schematic

Trans-conductance Operational Amplifiers

Trans-conductance operational amplifier [10], [14], [19] or OTA provides wide signal bandwidth for many amplifier circuits. In this amplifier, input voltage that is applied at the op-amp produces output current. There is an additional amount of current present that controls the trans-conductance of operational amplifier.

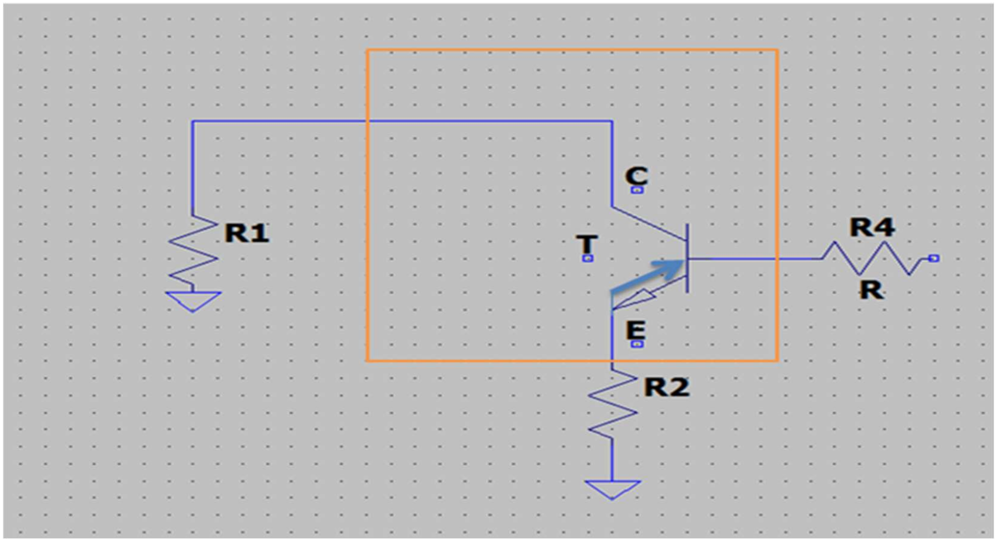


Figure 2 Basic Operational Trans-conductance Circuit Architecture

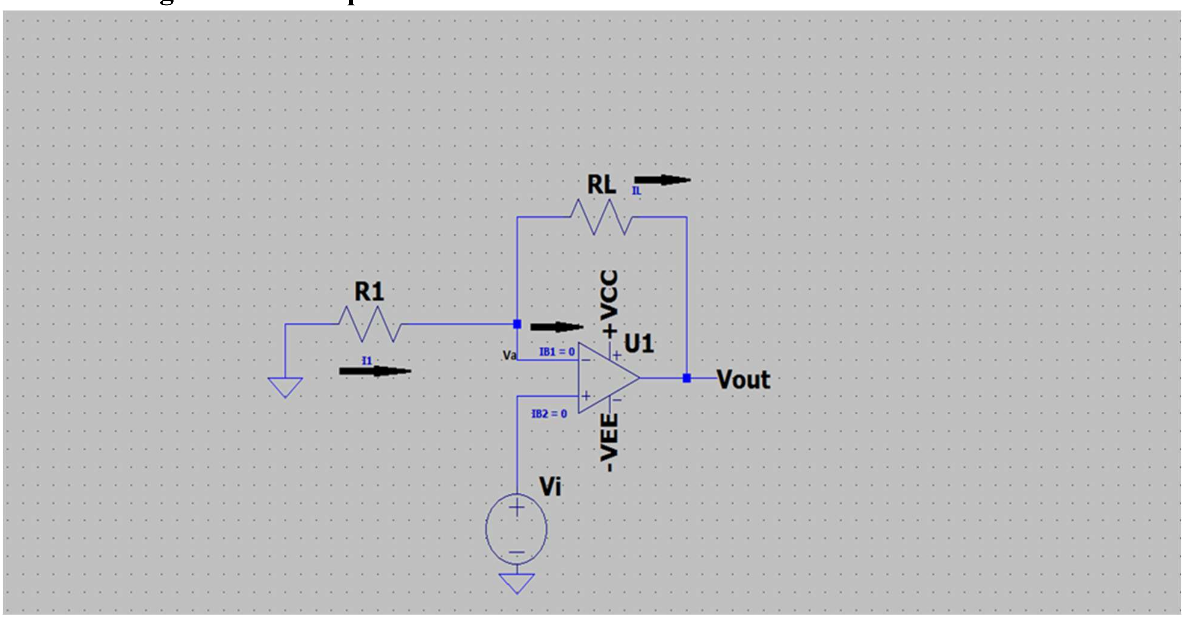


Figure 3 Trans-conductance Operational Amplifier

From figure 3, the equation for the output current from this circuit is given as

At point ‘a’

$$V_a = V_i \quad \text{--------} \ (1)$$

And

$$I_{B1} = I_{B2} = 0 \ \text{--------} \ (2)$$

Using Kirchhoff’s current law, we have

$$I_1 = I_{B1} + I_L \text{ ---------- } (3)$$

From equation (2)

$$I_1 = I_L$$

Current through Resistor R_1 is given by equation

$$I_1 = \frac{V_i}{R_1}$$

II. Literature Survey

A two stage op-amp based CMOS instrumentation amplifier has been presented using 0.13 μm CMOS fabrication technology [17]. The proposed circuit design is able to reduces the power dissipation by scaling down the supply voltage. The circuit is able to work on single power supply of 1.8 volt. The circuit design has three subsections where the first stage is differential gain, an additional gain stage and a bias string being an intermediate stage and last stage for the proposed circuit design respectively. Large value of circuit gain is achieved due to these three op-amp subsections. The overall current gain of 21.18dB with 6.32 MHZ unity gain bandwidth has been achieved from this proposed circuit.

Low amplitude ECG signals are more prone to interference in ECG recorder devices. Such interferences mainly caused by power line of the recording devices. A novel circuit implementation has been proposed which reduces such power line interferences and provide large CMRR and more gain [14]. The circuit provides reduction in power consumption of the circuit and input noise. The amplifier parameters such as CMRR of 135db, a voltage gain of value 41.8db and power consumption of 4.32 μW is achieved from proposed circuit implementation.

A 3 op-amps based current mode instrumentation amplifier has proposed [11]. The current mode topology is based on power supply current sensing techniques. Three commonly used current sensing techniques are based on inductor's resistance, MOSFETS and on sense resistors.

A three op-amp cascade structure has limited performance due to characteristics mismatch and issues in current mirror such as threshold voltage and process variations. The proposed circuit implementation solved these issues by utilizing the sense resistor in op-amp structure. The amplifier provides a CMRR of value 130db for the 87 Hz bandwidth and 93db gain. The circuit is well operated at 1.8 volt single power supply.

An OTA based CMOS IA is proposed for a biomedical application [12]. The three inputs OTA is belonging to voltage controlled current source. The proposed circuit has achieved large CMRR and PSRR with values 124db and 65bd respectively, low dc offset 0.3mVolts. The circuit shows power consumption of 0.52 mW.

III. Instrumentation Amplifiers

Development of efficient instrumentation amplifier [11], [12] in CMOS fabrication process has a number of advantages, including lower voltage and power requirements, more noise-resistant devices, the ability to incorporate complicated circuitry on a single silicon chip, and simple trans-conductor implementation. It is an integrated circuit that is used to amplify extremely weak signals. It is utilised in biomedical systems to correctly monitor bio potential signals since it is more resistant to noise removal. The following are significant properties of an instrumentation amplifier:

- Stable and accurate gain
- High CMRR
- High value input impedance, low value output impedance
- High slew rate

Traditional Instrumentation amplifier using 2 stage op- amp circuits is given below. It consists of two inverting and non-Inverting op-amps at the input stage and one output op-amp.

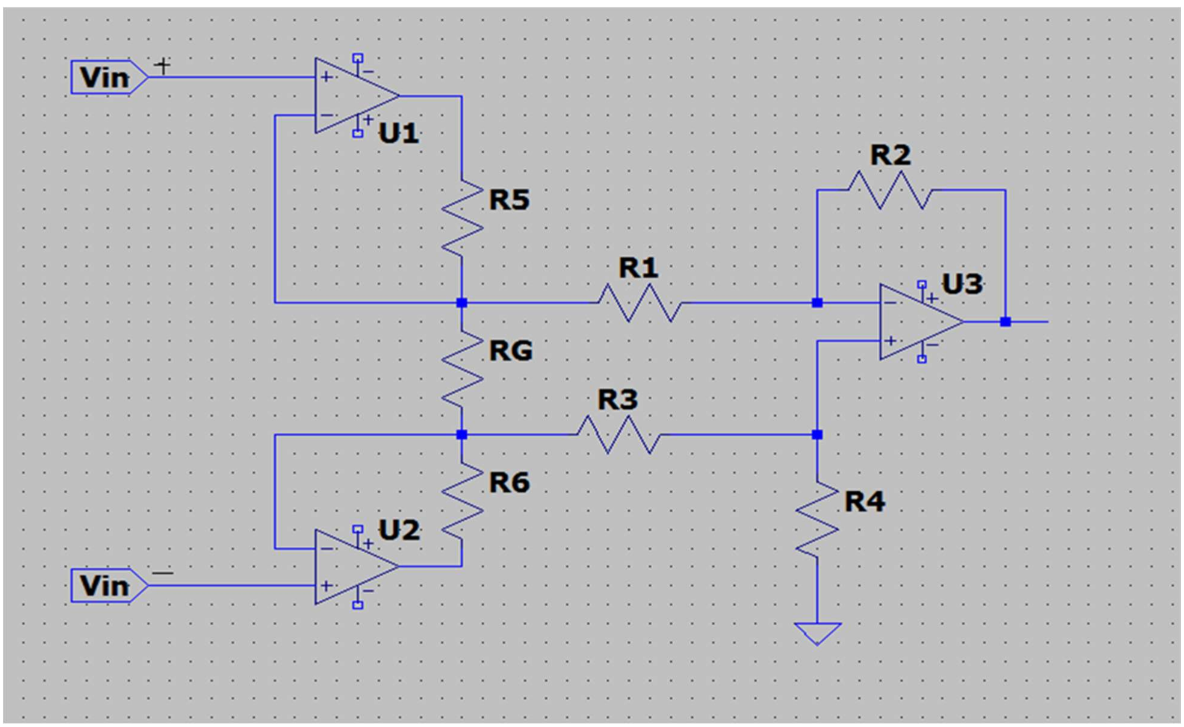


Figure 4 Traditional 2 stage Op-Amp Instrumentation Amplifier

The output voltage from the circuit shown in figure 4 is given by

$$V_{out} = \frac{R_2}{R_1}\left(\frac{2R_5}{R_G} + 1\right)(Vin_+ - Vin_-)$$

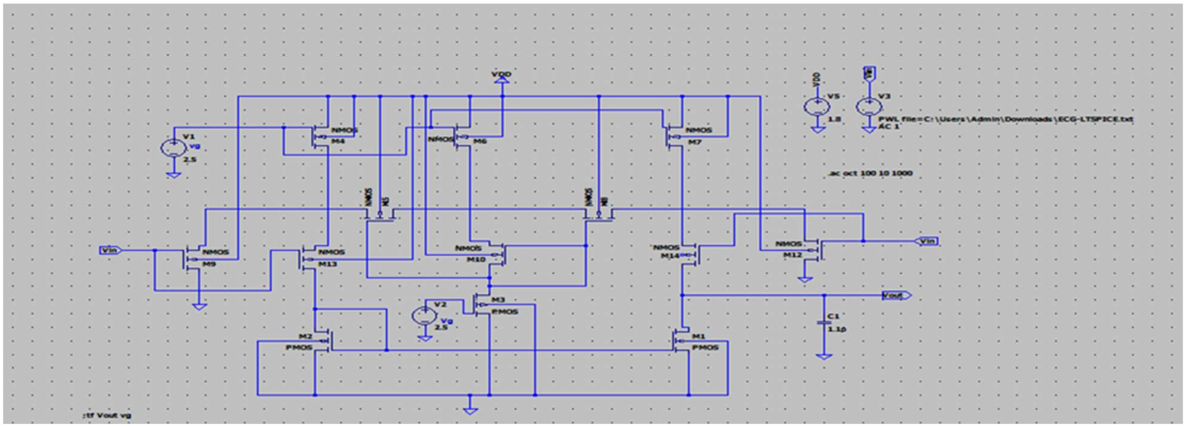


Figure 5.1 OTA Based CMOS Amplifier

IV. Implementation

The proposed work is concerned with testing the capability of an OTA-based instrumentation amplifier. Figure 5.1 depicts the schematic of an OTA-based CMOS amplifier. Three different bio-potential source signals are used for this purpose: ECG, EEG, and EMG. The piecewise linear voltage files are fed into an instrumentation amplifier's input. These source signals' amplification is investigated. In the same way, some common mode noise signals are mixed in with these source signals.

Figure 5.2 depicts the proposed circuit implementation, which employs three wideband OPA861 operational trans-conductance amplifiers. Two OTAs are used to build a differential amplifier input stage. The remaining trans-conductance amplifier is used to reverse the current. The current flowing through the differential amplifier is out of phase with the current flowing through capacitor C. For current collection, an op-amp-based integrator is used. An RC circuit is connected to avoid propagation delay.

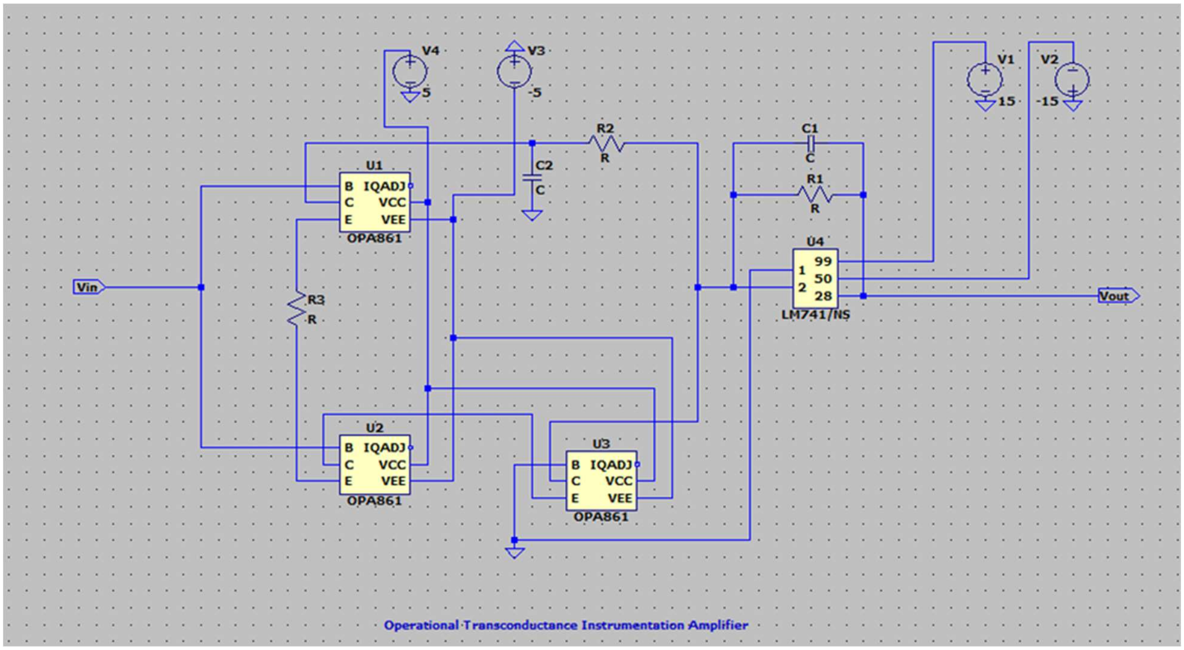
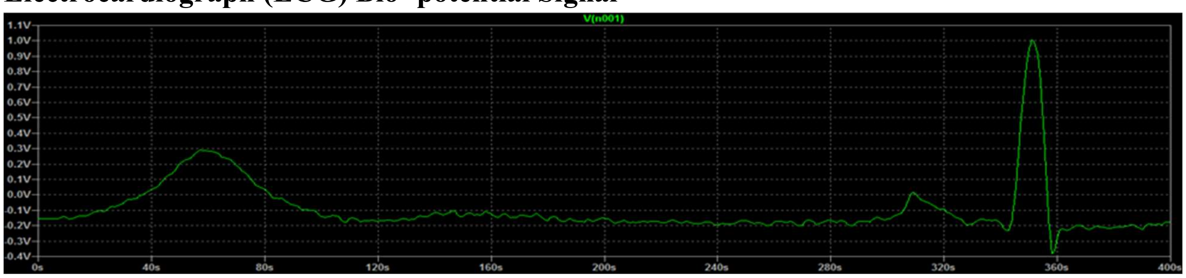


Figure 5.2 OTA Based Instrumentation Amplifier

V. Simulations

Electrocardiograph (ECG) Bio- potential Signal



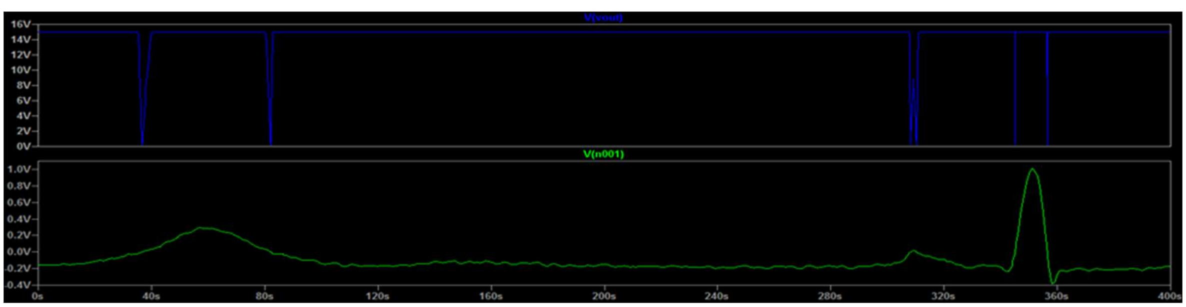


Figure 6.1 Input ECG Signal Source

ECG signal having amplitude ranging from -400 mv to 900 mv is applied to proposed instrumentation amplifier and output at a range of 14 volt is observed at the output of the instrumentation amplifier.

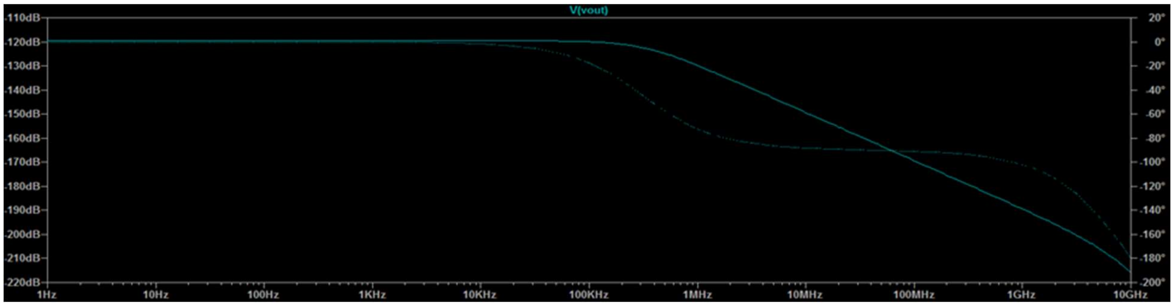


Figure 6.1.1 Frequency Response Curve of OTA Instrumentation Amplifier in Differential Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Differential mode ranging from 1Hz to 1GHz is plotted with maximum gain up to 120db is obtained.

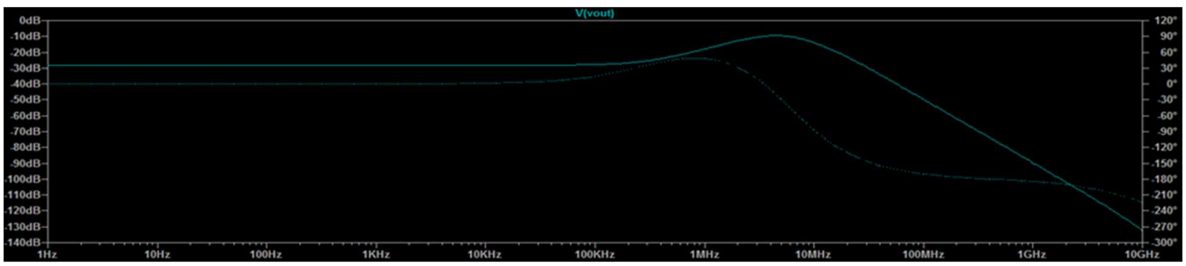


Figure 6.1.2 Frequency Response Curve of OTA Instrumentation Amplifier in Common Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Common mode ranging from 1Hz to 10GHz is plotted with maximum gain up to -10db is obtained.

Electroencephalography (EEG) Bio- potential Signal

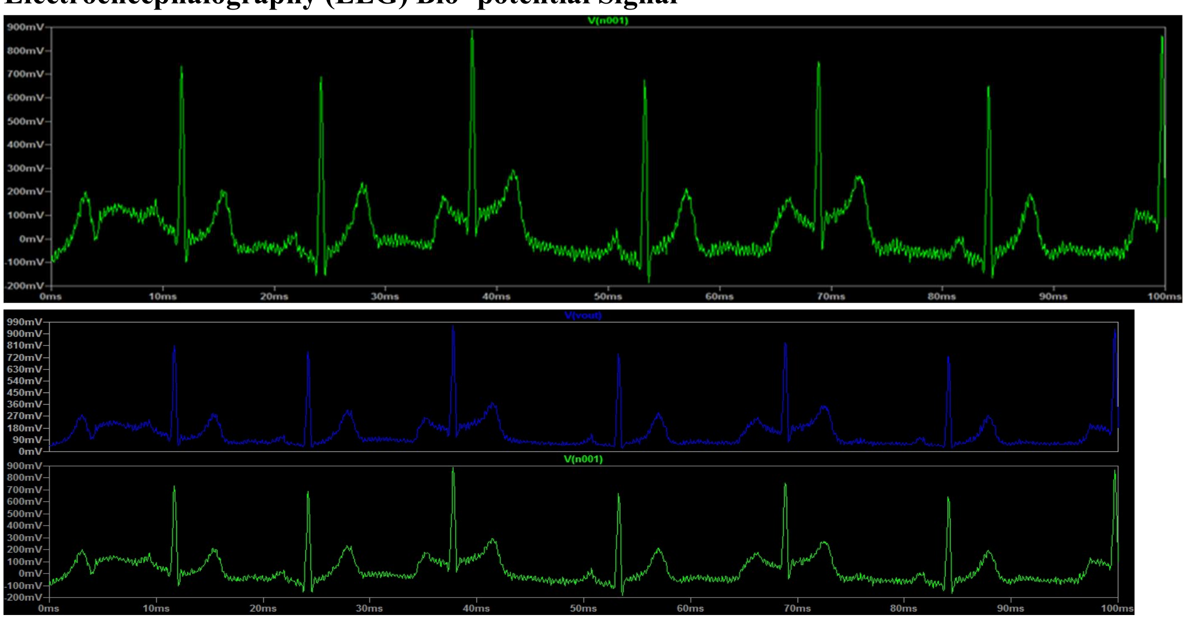


Figure 6.2 EEG Signal Source

EEG signal having amplitude ranging from -100 mv to 800 mv is applied to proposed OTA instrumentation amplifier and output at a range of 810mv is observed at the output of the instrumentation amplifier.

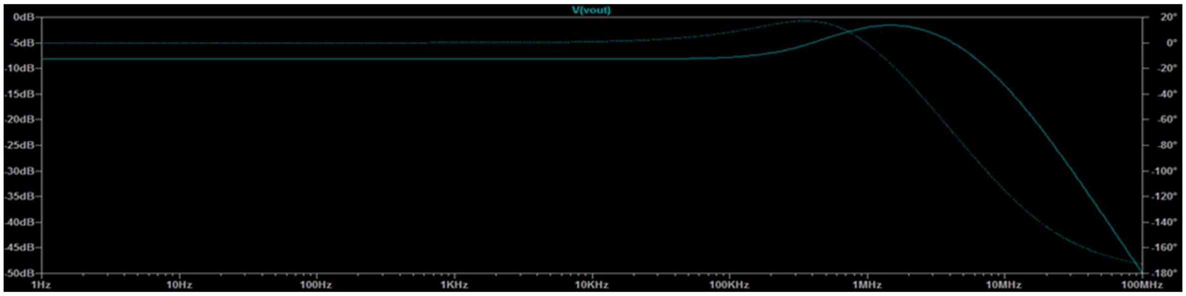


Figure 6.2.1 Frequency Response of OTA Instrumentation Amplifier in Common Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Common mode ranging from 1Hz to 100MHz is plotted with maximum gain up to -2db is obtained.

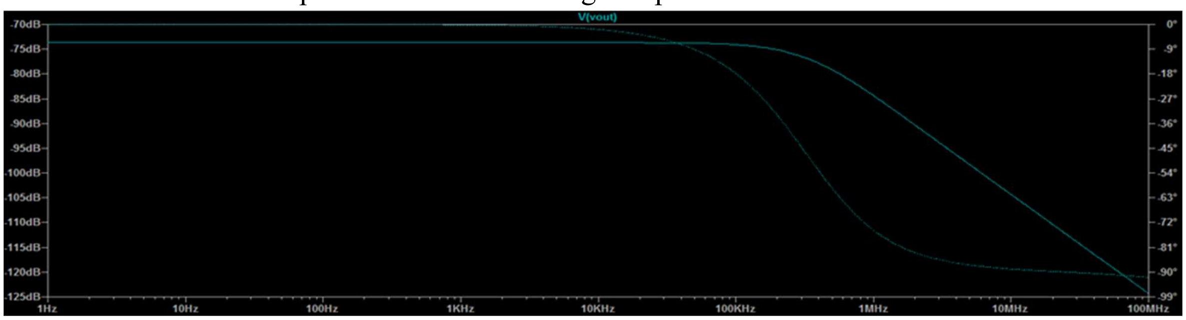
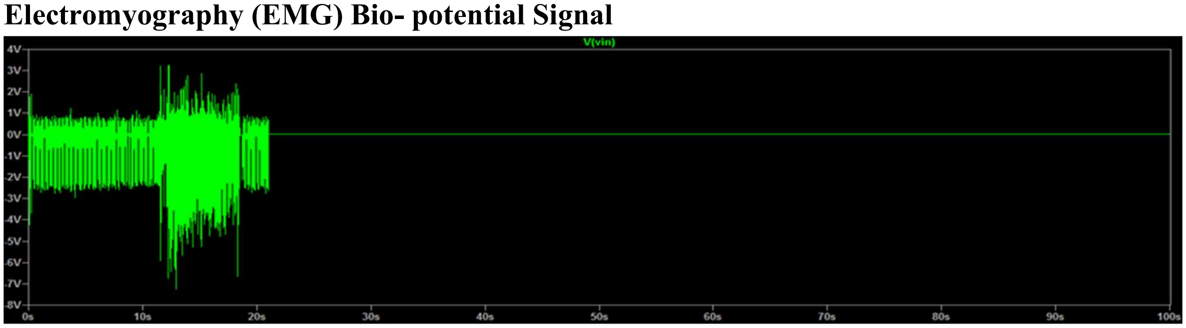


Figure 6.2.2 Frequency Response of OTA Instrumentation Amplifier in Differential Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Differential mode ranging from 1Hz to 100MHz is plotted with maximum gain up to -75db is obtained.

Electromyography (EMG) Bio- potential Signal



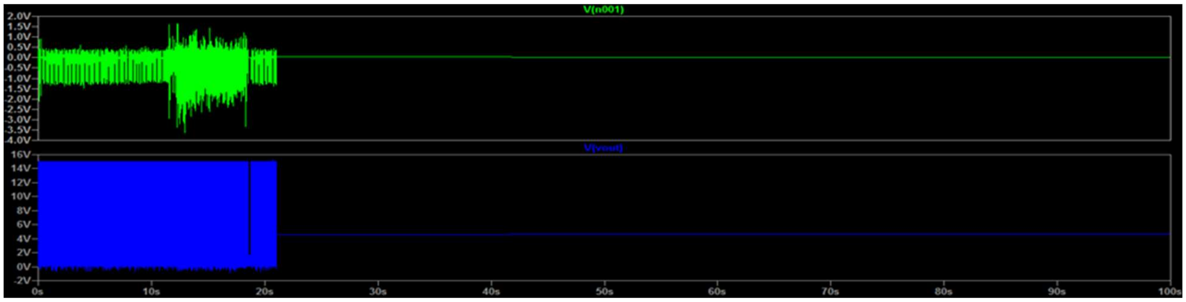


Figure 6.3 Input EMG Signal Source

EMG signal having amplitude ranging from -1mv to 1500 mv is applied to proposed instrumentation amplifier and output at a range of 14 volt is observed at the output of the instrumentation amplifier.

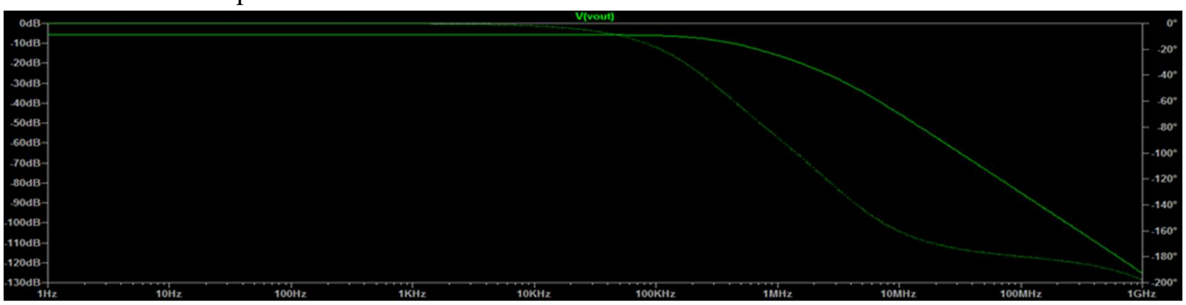


Figure 6.3.1 Frequency Response of OTA Instrumentation Amplifier in Differential Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Differential mode ranging from 1Hz to 1GHz is plotted with maximum gain up to -10db is obtained.

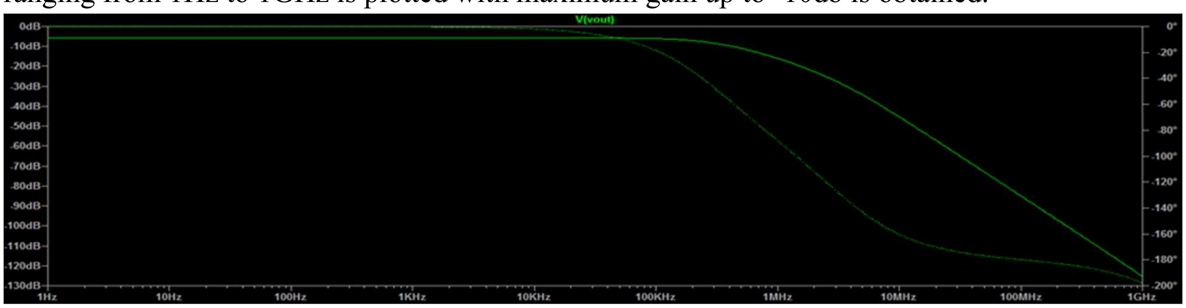


Figure 6.3.2 Frequency Response of OTA Instrumentation Amplifier in Common Mode Configuration

Frequency response of the proposed OTA instrumentation amplifier at Common mode ranging from 1Hz to 100MHz is plotted with maximum gain up to -1db is obtained.

VI. Observation Table

Instrumentation Amplifier Parameters	**ECG Bio-potential**	**EEG Bio-potential**	**EMG Bio-potential**
CMOS Technology	0.13 µm	0.13 µm	0.13 µm
Supply Voltage	1.8 V	1.8 V	1.8 V

Power Consumption	0.09 W	0.09 W	0.09 W
CMRR (DC)	54 dB	54 dB	54 dB
-3 db frequency BW for Differential signals	364.58 KHz	415.447 KHz	217.711 KHz
-3 db frequency BW for Common Mode signals	8.9724 MHz	674.8541 KHz	293.54 MHz

Table 1 Instrumentation Amplifier Parameter Values for Bio-potential Signals

VII. Conclusion

The operational Trans conductance amplifier based instrumentation amplifier has been implemented to analyze EGC, EEG and EMG bio potential signals. An instrumentation amplifier implemented has wideband OTAs with CMRR of value 54 dB and slew rate of 900 v/µs with operating bandwidth of 80 MHz The cut off frequency for ECG, EEG and EMG signals are measured as 364.58 KHz, 415.447 KHz and 217.711 KHz respectively. Operational Trans-conductance amplifier based instrumentation is suitable for such bio potentials analysis.

VIII. Future Scope

Future emphasis should be placed on improving the value of CMRR, as well as the implementation of complex bio-potential signals such as EEG and EMG bio-potential signals.

References

Alexander Hofmann, Michael Meister, Alexander Rolapp, Peggy Reich, Friedrich Scholz; Light Absorption Measurement with a CMOS Biochip for Quantitative Immunoassay Based Point-of-Care Applications; IEEE Transactions on Biomedical Circuits and Systems Volume 15, Issue 3, June 2021

Shubham Saurabh, Mujahid Saifi, Shylaja V. Karatangi, Amrita Rai; Design of CMOS Instrumentation Amplifier Using Three-Stage Operational Amplifier for Low Power Signal Processing; International Conference on Artificial Intelligence: Advances and Applications 2019. Algorithms for an Intelligent Systems. Springer, Singapore

Buddhi Prakash Sharma, Rajesh Mehra; Design of CMOS instrumentation amplifier with improved gain & CMRR for low power sensor applications; 2nd International Conference on Next Generation Computing Technologies, IEEE, 14-16 October 2016

Girinath, Dr. Ganesh Babu, Mr. Dinesh Kumar JR, Mr. SP Karthi; A Novel Low Noise Instrumentation Amplifier for Biomedical applications; IOP Conf. Series: Materials Science and Engineering, ICCSSS 2020

Frederick Ray Gomez, Lendl Israel Alunan, Sherwin Paul Almazan, John Martin Jarillas, Maria Theresa De Leon, Marc Rosales; Current Mode Instrumentation Amplifier using 0.25 µm CMOS Process for ECG Signals; Global Journal of Engineering Science and Research Management, Thomas Reuters, ISSN: 2349-4506, February 2019

M.Y. Ren, C.X. Zhanga, D.S. Sun; Design of CMOS Instrumentation Amplifier; Elsevier, International Workshop on Information and Electronics Engineering, 4035 – 4039, 2012

R M Rangayyan; Biomedical Signal Analysis; John Wiley and Sons, 2015

John Mulindi; Basics of Biomedical Instrumentation Systems, February 27, 2015

R.V. Saranya, R. Sureshkumar; CMOS Instrumentation Amplifier for Biomedical Applications; International Journal of Engineering Research and Modern Education, ISSN: 2445-4200, Volume 2, Issue 1, 2017

Shireen T. Sheikh, D.J. Dahigoankar, Hemant Lohana; Comparative Analysis of CMOS OTA; IOSR Journal of VLSI and Signal Processing, ISSN: 2319 – 4200, ISBN No. : 2319 – 4197 Volume 1, Issue 3, November - December 2012

Gaytri Gupta; Designing of Current Mode Instrumentation Amplifier for Bio-signal using 180 NM CMOS Technology; International Journal of Electrical, Electronics and Data Communication, ISSN: 2320-2084, Volume 2, Issue 1, January 2014

Shweta Karnik, Pramod Kumar Jain, D. S. Ajnar; Design of CMOS Instrumentation Amplifier for ECG Monitoring System Using 0.18 µm Technology; International Journal of Engineering Research and Applications, ISSN: 2248-9622, Volume 2, Issue 3, May-June 2012

Lee Cha Sing1, N. Ahmad1, M. Mohamad Isa1, F. A. S. Musa; Design and analysis of folded cascode operational amplifier using 0.13 µm CMOS technology, The 2nd International Conference on Applied Photonics and Electronics 2019

Yuze Yang; Design of low power low noise CMOS ECG Amplifier for Smart Wearable Device; Journal of Physics, AIAAT 2020

Hassan Jassim; A New Design Technique of CMOS Current Feed Back Operational Amplifier; SciRes, Circuits and Systems, 2013

Kandi Praveen Kumar, D. Vaithiyanathan; Design and analysis of a three stage CMOS op-amp using indirect feedback compensation, First International Conference on Advances in Physical Sciences and Materials, Journal of Physics: Conference Series, 2020

K.T. Tan, N. Ahmad, M. Mohamad Isa, F.A.S. Musa; Design and Analysis of Two Stage CMOS Operational Amplifier using 0.13 µm Technology, The 2nd International Conference on Applied Photonics and Electronics, 2019

Joachim H. Nagel; Biopotential Amplifiers; The Biomedical Engineering Handbook: Second Edition

C. S. Sajin, M. R. Ramrosh, and T. A. Shahul Hameed; Design and Simulation of Current Feedback Operational Amplifier in 180nm and 90nm CMOS; ICTACT Journal on Microelectronics, Volume 03, Issue 02, July 2017

A. Soliman, Mahmoud, Inas A. Awad; Fully Differential CMOS Current Feedback Operational Amplifier, Springer, Analog Integrated Circuits and Signal Processing, 43, 61–69, 2005

Johan F. Witte, Johan H. Huijsing, Kofi A. A. Makinwa; A Current-Feedback Instrumentation Amplifier With 5 µV Offset for Bidirectional High-Side Current-Sensing, IEEE Journal of Solid State Circuits, Volume 43, No. 12, December 2008

A.O.Mulani and P.B.Mane, "An Efficient implementation of DWT for image compression on reconfigurable platform", International Journal of Control Theory and Applications, Vol.10 No.15, 2017.

S. S. Swami and A. O. Mulani, "An efficient FPGA implementation of Discrete Wavelet Transform for image compression", International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS),2017

A.O.Mulani and P.B.Mane, "Area Efficient High Speed FPGA Based Invisible Watermarking for Image Authentication", Indian Journal of Science and Technology, Vol.9. No.39, Oct. 2016.

P. B. Mane and A. O. Mulani, "High Speed Area Efficient FPGA Implementation of AES Algorithm", International Journal of Reconfigurable and Embedded Systems, Vol. 7, No. 3, November 2018, pp. 157-165

A.O.Mulani and Dr.P.B.Mane, "Fast and Efficient VLSI Implementation of DWT for Image Compression", International Journal for Research in Applied Science & Engineering Technology, Vol.5 Iss. IX, pp. 1397-1402, 2017.