



Design And Performance Analysis of Multipath Differential Operational Transconductance Amplifier for ECG Signal

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Abstract: Biomedical signals are employed to implement the hidden physiological mechanisms of some biological system or phenomenon. Inadequate analysis or improper interpretation of such signals may, in fact, result in unfavorable consequences, ranging from causing injury or death. A death rate of nearly 18 million is registering annually. Analysis of the signals provides the impression of the diseases of heart, brain and all other body parts. An Operational Transconductance Amplifier (OTA) is very suitable for explanation of these signals. In general, these biomedical signals are experiencing the low frequency and amplitude ranges. In this project, the OTA is implemented according to the specifications, with the help of CMOS Technology. The performance analysis can be achieved by providing a biomedical signal as a test signal to the input of the OTA. The tools employed for this OTA design are Cadence software, DSCH & Microwind. Multipath differential Operational Transconductance Amplifier is designed, the frequency response will be plotted and its performance analysis can be carried out by calculating with the available amplifier configurations such as current mirror symmetrical OTA & cascaded current mirror symmetrical OTA. The OTA is established for figures of merit like high CMRR, gain, etc., using OTA in biomedical signal amplification would result in an increased accuracy in the output. Such outputs under correct interpretation would assist the complications of the very important organs of the body thus enhancing the rate of mortality.

Index terms: Multipath differential Operational transconductance amplifier (OTA), common mode rejection ratio, gain, cadence software, DSCH & Microwind.

I. INTRODUCTION

Cardiovascular disease continues to be one of the principal causes of mortality in the industrialized world, and SCA is responsible for nearly 50% of these, which equates to 350,000–400,000 deaths annually. Monitoring regularly using electrocardiograms (ECGs) effectively lowers these mortality rates by diagnosing heart disease. ECGs record the electrical signals and rhythm of the by using electrodes on the skin, allowing it to detect ailments such as arrhythmias, ischemia, and myocardial infarction. Nonetheless, noise artifacts in ECG signals, which frequently occupy overlapping frequency ranges, impede precise analysis. Operational Transconductance Amplifiers (OTAs) play an important role in overcoming such problems by amplifying ECG signals with less noise. OTAs are current sources controlled by voltage, reducing 1/f noise and suited best for use in ECGs. OTAs of various forms, such as two-stage Miller, telescopic cascode, folded cascode, and current mirror OTAs, are implemented. Out of these, multipath differential OTAs are recognized for their innovative architecture with more transconductance, linearity, and bandwidth, coupled with better noise suppression, gain, and stability. Multipath differential OTAs are superior to conventional cascaded current mirror OTAs, which, although they are power and transistor efficient, lack good frequency response and gain

in submicron technologies. The unique feedback structure of the multipath differential OTA provides enhanced bandwidth, linearity, noise immunity, and stability and is thus the best choice for robust ECG signal amplification even in submicron nodes. Its performance competence under such situations proves its superiority. This project is aimed at designing and testing a multipath differential OTA in 90nm technology to address the needs of modern biomedical signal processing. Through optimization of key parameters such as power consumption, Common Mode Rejection Ratio (CMRR), bandwidth, and DC gain, the multipath differential OTA offers a strong and optimized design for ECG applications. Its improved performance guarantees precise diagnostics, enhancing biomedical technology and patient care.

1.1 Aim of the Project

The aim of this project is to design and analyse the performance of the existing amplifier to the robust amplifier namely multipath differential operational transconductance amplifier in cadence virtuoso analogue design environment and to implement the OTA by feeding an ECG signal equivalent within the frequency range of it, to obtain its frequency response and to show the performance evaluation. Finally, to draw the layout of the OTA.

Methodology

A multipath fully differential Operational Transconductance Amplifier (OTA) is chosen for its better performance parameters. The design, which is carried out using Cadence tools in 90nm technology, provides better common-mode rejection, better linearity, and higher bandwidth, critical for precise ECG signal processing. Thorough analysis, such as gain, performance, and transient response, will be performed to assess the OTA's performance for ECG applications. In addition, a detailed layout will be created using Cadence. Working in the range of critical frequency of about 100Hz, this multipath fully differential OTA seeks to deliver a high fidelity amplified ECG signal that aids in the early detection of cardiac anomalies and can help lower sudden cardiac arrest-related deaths.

II. DESIGN OF PROPOSED METHOD

A fully differential Operational Transconductance Amplifier (OTA) with multiple parallel signal paths is presented in this project. This topology has the use of several parallel paths and fully differential structure. It is intended to enhance bandwidth and slew rate with high linearity. This topology finds its application in high-speed data converters and precise analog signal processing. It is challenging to handle more than one path and matching. A multipath fully differential OTA multipath is designed and simulated in Cadence for a 90nm technology. Performance will be analysed to test gain, bandwidth, phase margin, CMRR, and power. A comparison with other existing fully differential OTAs will be made. High gain, high bandwidth, and low distortion are the design requirements. Cadence will be used to generate layout, keeping parasitic effects at a minimum. The OTA works in a 10Hz - 100Hz bandwidth, targeting high-speed analog-to-digital converters. The objective of designing and testing a multipath fully differential OTA is to obtain bandwidth, linearity, and signal integrity improvements. Multiple signal paths are implemented so that the design will enhance performance while capturing the benefits of a fully differential architecture. The performance will be tested through simulations and post-layout analysis to prove the design.

2.1 Design Equations

The specifications that need to obtain an effective amplifier for ECG signal are discussed here.

Some of the important design equations are as follows:

1. Drain Current of Transistor M1a

$$I_{D, 1a} = \beta_{1a, b/2} * (\sqrt{(2I_B/\beta_{1a, b}) + V_{id}})^2 \quad \dots\dots\dots (1)$$

$\beta_{1a, b}$ = Transconductance parameter of M1a

I_B = Bias current

V_{id} = Input Differential voltage

Change of M1a ($I_{D, 1a}$) to the input voltage (v_i)

$$(I_{D, 1a}/V_i) \approx -2g_{m, 1a}$$

$G_{m, 1a}$ = transconductance at transistor M1a

Voltage gains from input to node A

$$(V_A/V_i) \approx -2g_{m, 1a}/g_{m, 3a}$$

Transconductance of path created by M3b

$$(ID_{3b}/V_i) \approx -gm_{3b}$$

Drain Current of the transistor M3b(ID_{3b})

$$ID_{3b} = (\beta_{3b}/\beta_{3a}) (IB + ID_{1a})$$

2. Small-Signal Transconductance (G_m):

$$G_m \approx \frac{2gm_{1a} + gm_{3c} + gm_{3b} * (gm_{7b} + gm_{7c})}{(gm_{7a} - gm_{7d})} \dots\dots\dots (2)$$

gm_i = Transconductance of transistor M_i .

gm_{1a} = Transconductance of the main input transistor.

$$gm_{1a} = \sqrt{2 * \beta_{1a} * Id_{1a}} \text{ or } gm_{1a} = \frac{2 * Id_{1a}}{V_{od_{1a}}}$$

$$\beta_{1a} = C_{ox} * \mu * (W/L)_{1a}$$

Id_{1a} = the drain current of M1a.

$V_{od_{1a}}$ = the overdrive voltage of M1a.

gm_{3c} = Transconductance of the PMOS load transistor.

gm_{3b} = Transconductance of the path created by M3b.

gm_{7a} , gm_{7b} , gm_{7c} , gm_{7d} = Transconductance of the NMOS load transistors and the Positive feedback transistors.

Simplified Equation

$$G_m = 2 * (1 + q + s * (n + m) / (1 - k)) * gm_{1a} \dots\dots\dots (3)$$

q , s , n , m , k = current gain parameters of the current mirrors.

Assuming the same overdrive voltage, V_{od} , for all transistors, that relationships between the gm values can be represented by the coefficients q , s , n , m , and k .

GBW (Gain Bandwidth) Equation:

$$GBW = G_m / (2 * \pi * CL)$$

$$GBW = \frac{2 * (1 + q + s * (n + m) / (1 - k)) * gm_{1a}}{(2 * \pi * CL)} \dots\dots\dots (4)$$

CL = Total Capacitance which includes external capacitance parasitic capacitance from the transistors.

3. Pole Locations (ω_A , ω_C):

$$\omega_A \approx \frac{-gm_{3a}}{((1 + s + q) * CGS_{3a})} \dots\dots\dots (5)$$

CGS_{3a} = the gate-source capacitance at transistor M3a.

$$\omega_C \approx \frac{-(gm_{7a} - gm_{7d})}{((1 + n + m + k) * CGS_{7a})} \dots\dots\dots (6)$$

CGS_{7a} = the gate-source capacitance at transistor M7a.

2.1 Circuit Diagram of Multipath Differential OTA

The circuit shown in Fig1 is a multipath differential OTA used for low-voltage ECG signal amplification. The circuit is implemented using 90nm CMOS technology, which is selected for its trade-off between performance and power consumption. The main aim is to develop an OTA for continuous cardiac monitoring with the focus being on the very important requirement of early detection of cardiac anomalies. The "multipath" feature of the design is the presence of multiple signal paths in the amplifier, a method that provides greater bandwidth and gain over single-path designs. The design permits increased gain, which are critical for capturing the transient character of ECG signals. The input stage utilizes a PMOS differential pair (M1a/M1b and M2a/M2b), which is highly low-noise, essential for amplifying the weak ECG signals. These PMOS transistors are dimensioned with $9\mu\text{m}$ width and $0.9\mu\text{m}$ length, trading gain and input capacitance. The current mirrors (M3a/M3b and M4a/M4b) are vital for providing stable bias currents, ensuring that the amplifier performs consistently. They're sized at $4.5\mu\text{m}$ in width and $1.8\mu\text{m}$ in length. This scaling fine-tunes the biasing network and improves both the gain and output impedance of the OTA, all while sticking to the limitations of 90nm technology. Plus, the smaller dimensions lead to lower parasitic capacitance, which helps achieve higher bandwidth. The CMFB network (M5a to M8e) plays a crucial role in stabilizing the common-mode output voltage, keeping the amplifier within its linear operating range. In the 90nm tech, these transistors are thoughtfully designed with a width of $3\mu\text{m}$ and a length of $1.8\mu\text{m}$. This careful sizing ensures that the CMFB circuit has enough loop gain and bandwidth to quickly and accurately adjust for any common-mode variations. The positive feedback transistors (M7d and M8d) boost the CMFB network's effectiveness without sacrificing stability.

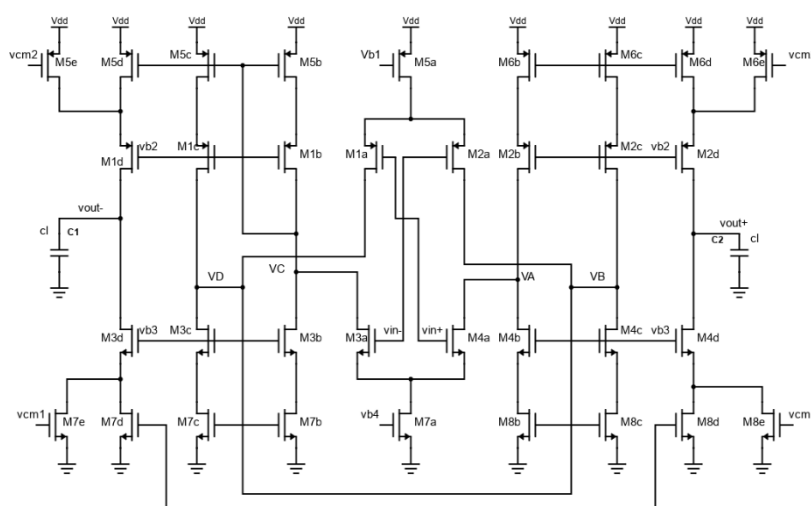


Fig1: circuit diagram of multipath differential OTA

Lastly, the Flipped Voltage Follower (FVF) cells (M3a/M3b and M4a/M4b) enhance the overall gain and stability of the amplifier while keeping headroom requirements to a minimum—this is especially important for low-voltage designs. These transistors are scaled appropriately to optimize the balance between output swing, stability, and power efficiency.

To remove this limitation, flipped voltage-follower (FVF)-based differential structures were used to provide a variable tail current source by which the dynamic current can be increased, depending on the input signal amplitude. It means that two FVF-based differential structures are configured, by which some idle devices, PMOS load transistors, are adaptively biased as new drivers, resulting in an enhancement in the small-signal transconductance too. Due to the use of an additional path taken from the FVF cells again, the NMOS load transistors are also used as new drivers to re-increase the transconductance. Employing these techniques causes a class-AB operation significantly improves the driving capability of the circuit such that a high SR is achieved. In addition, a positive feedback circuit is added to the NMOS current mirrors, thus improving both dc and transient characteristics. Combining the above-mentioned techniques enhances the circuit performance. Thus, such a combination may be one of the best options among other effective structures.

III. IMPLEMENTATION

The circuit schematic as in Fig2 was designed in cadence virtuoso analogue design environment. All the transistors were accessed from the gpdk090 technology library. Then the symbol as in Fig 3&4 was created for current mirror OTA with 2 inputs (v_{in+} & v_{in-}) and 2 outputs and 2 supply pins. Two supply voltages were provided positive voltage of 1.8V for VDD and negative of -1.8V for VEE.

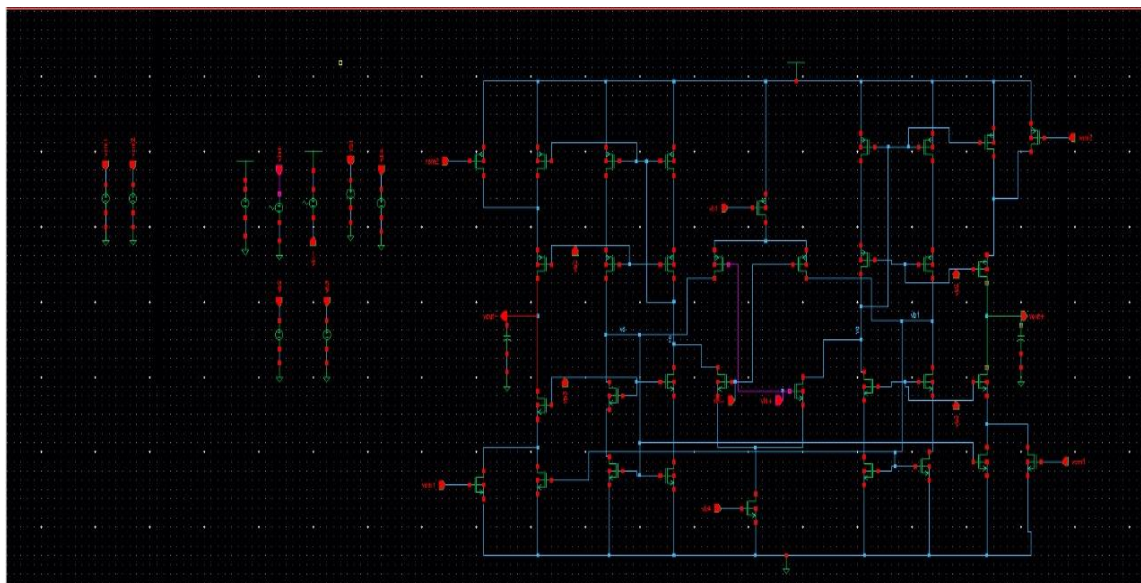


Fig2: circuit in cadence

For differential input a sinusoidal voltage of 2mv amplitude and 100 Hz frequency was used at one input and other input of -2mv amplitude and 100Hz frequency was used to take measurement of the differential gain. For common input sinusoidal voltage of 2mv amplitude and 100 Hz frequency was given at both the inputs of the OTA.

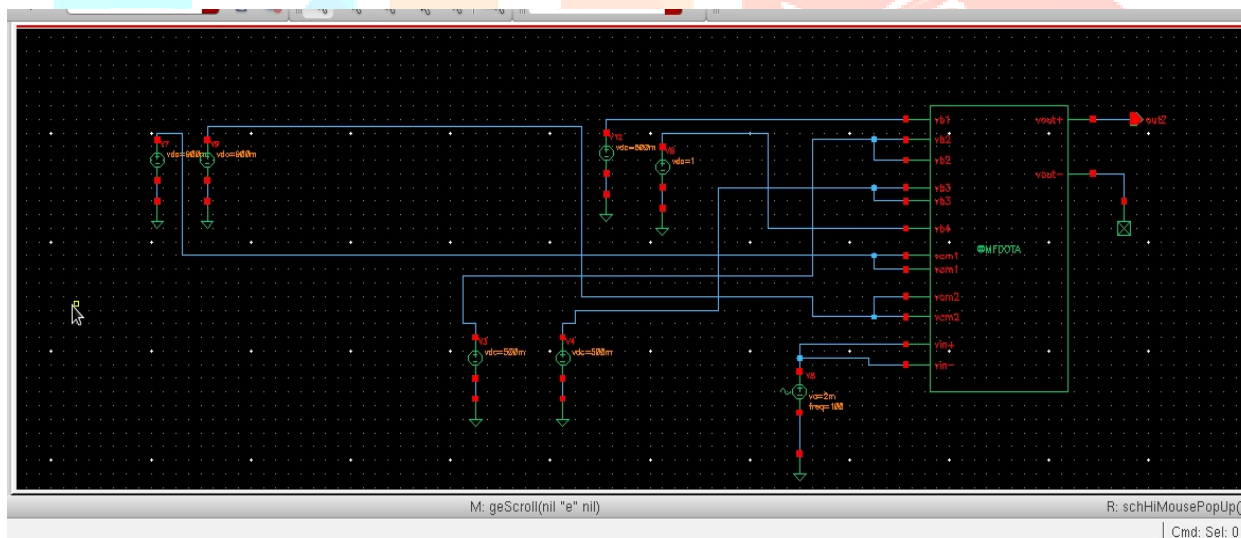


Fig3: test bench for common input

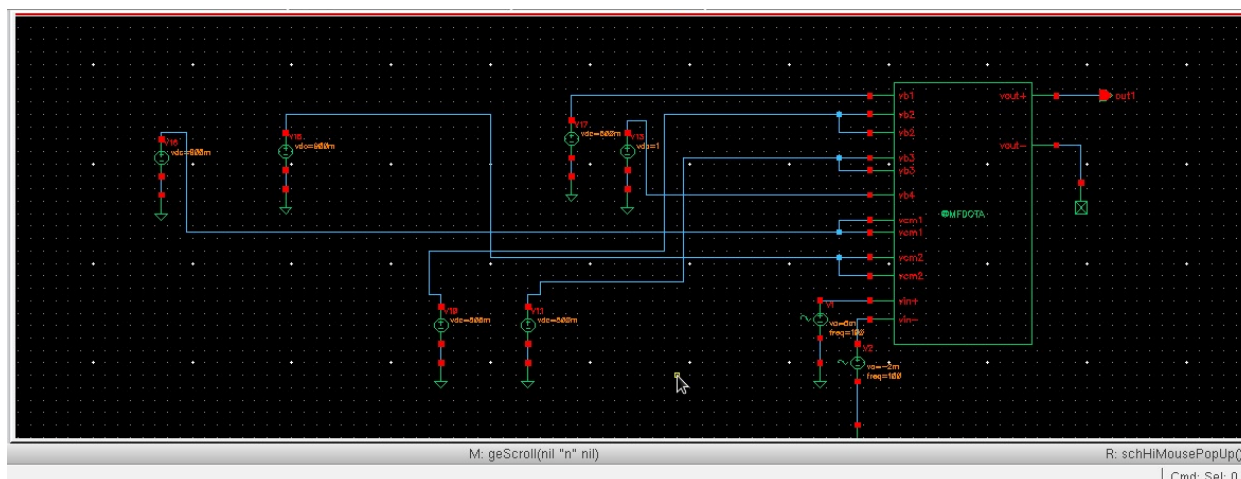


Fig4: test bench setup for differential input

IV. RESULTS

4.1 Transient Analysis

The operational transconductance amplifier (OTA) was simulated using the Cadence Virtuoso analog design platform to carry out transient analysis. Differential input signals with ECG-simulated patterns (2mV amplitude, 100Hz frequency, opposite sign) produced an output signal of 1.6V with amplification. The analysis revealed the multipath differential OTA performed better than the cascaded current mirror OTA variant.

Transistor analysis investigates circuit response in transition between stationary states, such as voltage/current response to driving transitions. Capacitance and inductance, both parasitics, can influence circuit response, leading to departures from desired design. The technique is also applied to ensure circuit operation using various voltage sources.

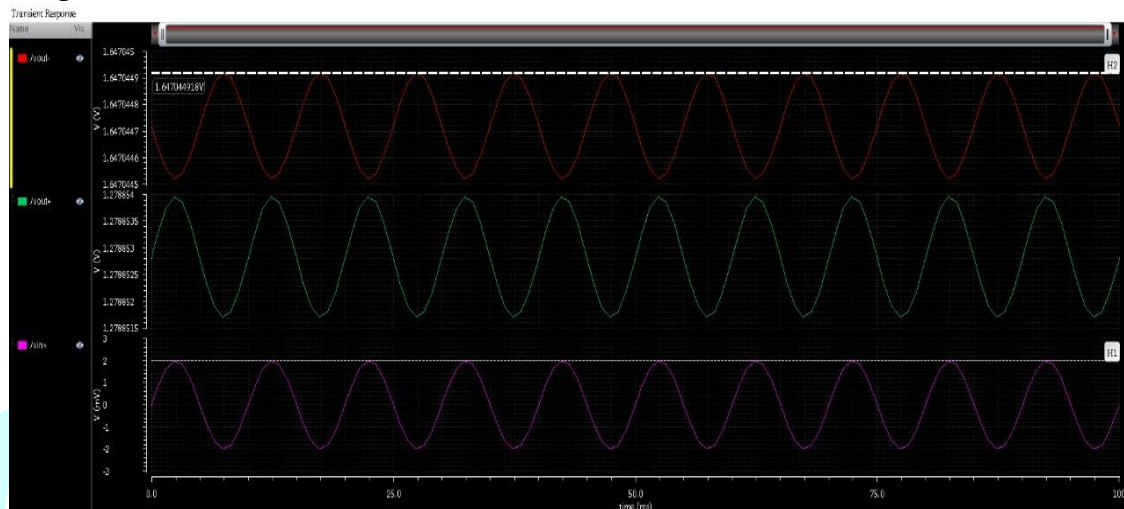


Fig5: transient analysis

4.2 AC Analysis

The AC response of the multipath differential OTA was simulated in Cadence Virtuoso. An AC response of 1.067V was observed, graphically represented in Fig 6. The performance of the OTA is subject to the application requirements, such as frequency range and signal dynamics. To effectively amplify ECG signals, the OTA has to attain an open-loop gain above 58dB. For differential gain, 2mV and -2mV AC signals were fed to the OTA inputs. AC analysis examines the behavior of a circuit in relation to alternating current signals and gives voltage/current versus frequency information. It is used to find the frequency response, defined by the transfer function, which indicates amplitude and phase variation at various frequencies. The results are usually presented as Bode plots. This technique, essential for the design of filters, amplifiers, and other analog circuits, determines the best operating ranges and possible problems such as distortion. AC analysis can be done by simulation software such as SPICE or by mathematical calculations.

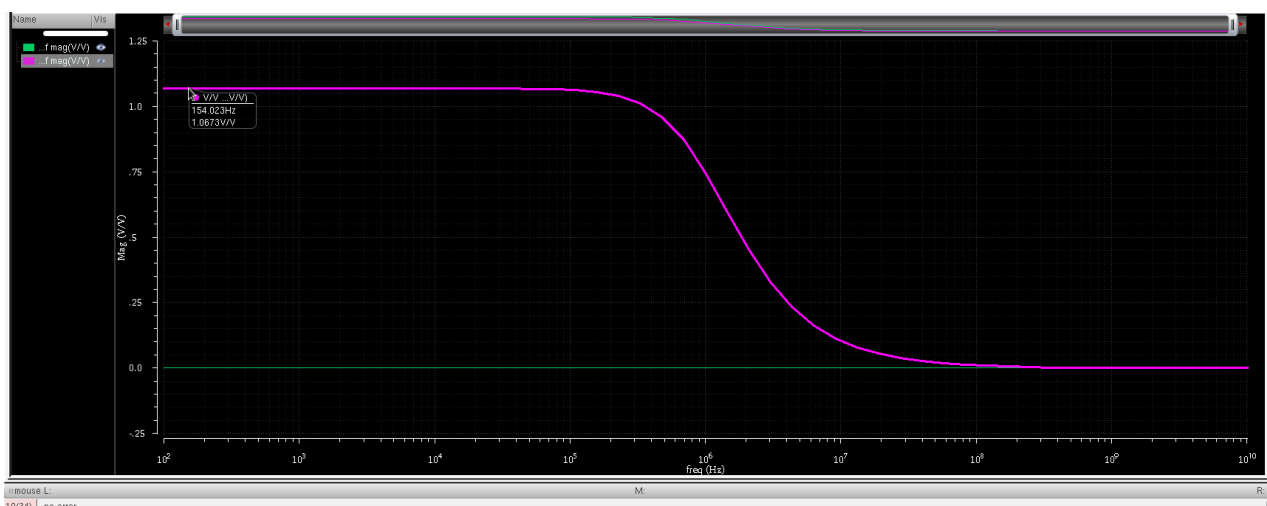


Fig 6: AC response

4.3 Power Analysis

Power analysis analyses power consumption and dissipation in circuits, a requirement for designing power-efficient devices and determining thermal limits. It requires measuring or estimating power consumed by every element, summing power, and integrating instantaneous power over time to determine the average. Power dissipation, or heat loss, is a concern for high-power devices to avoid damage and wastage. The multipath differential OTA circuit used $246.8\mu\text{W}$ from a supply of $\pm 1.8\text{V}$, demonstrating its portability and battery operability. Cadence Virtuoso was used to examine total power consumption, yielding useful information for design optimization

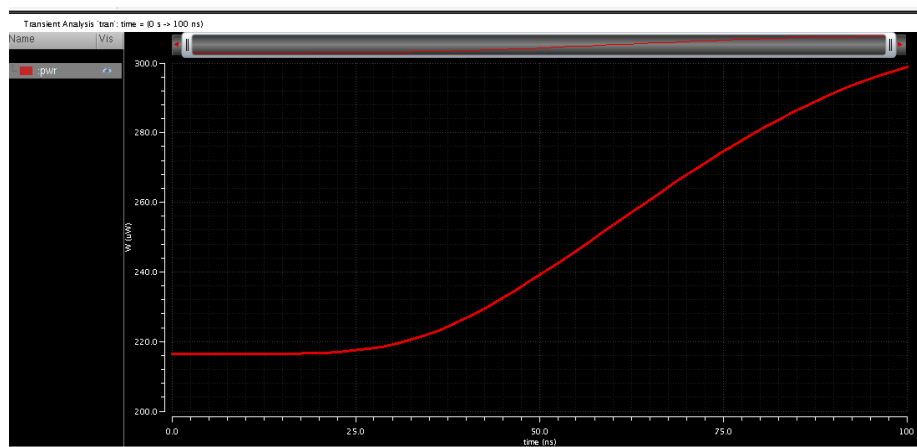


Fig7: power analysis

4.4 Noise Analysis

Noise analysis assesses the effect of unwanted signals (e.g., thermal noise, flicker noise, shot noise, EMI) on electronic circuits. It is essential for developing dependable systems since noise can induce errors and distortion. Time-domain measurement determines noise amplitude and length, whereas frequency-domain analysis determines spectral content and system frequency response to detect and solve noise. The multipath differential OTA shows outstanding noise performance with a noise power spectral density of $46.14\text{ pV}^2/\text{Hz}$ at 100.8 Hz , making it perfect for weak-signal applications such as ECG acquisition. Its design reduces thermal and flicker noise, improving clarity and accuracy. The differential topology enhances common-mode noise rejection, minimizing interference and power supply variation effects. High linearity is responsible for undistorted amplification of ECG signals, and low power consumption is advantageous for portable and battery-powered applications. Input noise and output noise levels of $39.541\text{ pV}/\text{Hz}$ and $46.13\text{ pV}/\text{Hz}$ were witnessed, validating the OTA's suitability for high-performance medical devices. It surpasses most topologies in noise attenuation, linearity, and energy efficiency.

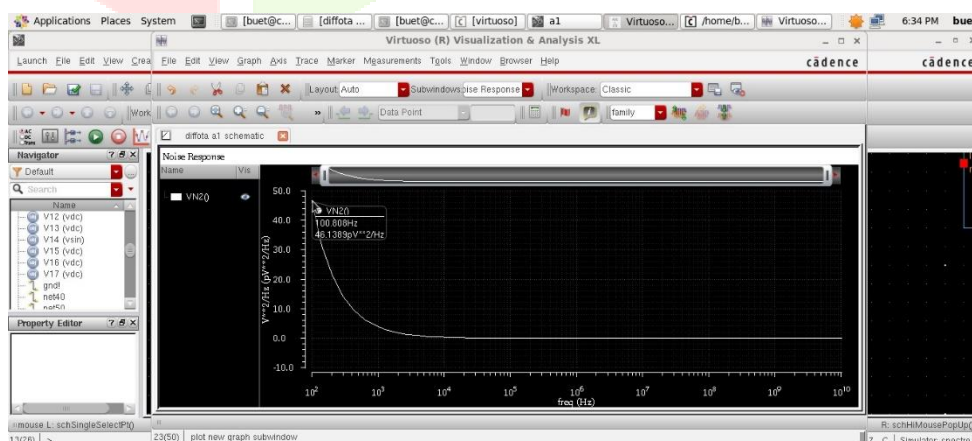


Fig8: output noise response



CMRR in Virtuoso is a measure of an amplifier's ability to reject the common mode signals while amplifying differential signals. For instrumentation and differential amplifiers, it is a critical performance metric. Virtuoso supports CMRR simulations via tests and analysis to determine amplifier performance under different conditions and input signals


$$\text{Differential Gain (dB)} = 20 \times \log_{10}(V_{out} / V_d) \dots\dots\dots (7)$$

$V_{out}=3.28 \text{ V}$ (from output waveform)
 $V_{in+}=2 \text{ mV}=0.002 \text{ V}$ (from input waveform)
 $V_{in-}=-2 \text{ mV}=0.002 \text{ V}$ (from input waveform)
 $\text{Differential Voltage}(v_d) = (V_{in+}) - (V_{in-})$
 $\text{Differential Voltage}(v_d)=4\text{mV}$
 Substituting values in the equation:
 $\text{Gain (dB)}=20 \times \log_{10}(3.28/0.004)$
 $\text{Gain(dB)}=20 \times \log_{10}(820)$
 $\text{Gain (dB)}=20 \times 2.9138$
 $\text{Gain (dB)} \approx 58.28 \text{ dB}$

The common mode gain (CMRR) of a multipath Operational Transconductance Amplifier (OTA) is a measure of its rejection of common mode signals at the two inputs. In a single-stage multipath differential OTA, parameters like transistor matching, design of the input differential pair, and the feedback network play major roles in its common mode gain. The common mode gain for this multipath differential OTA is -133.8dB.

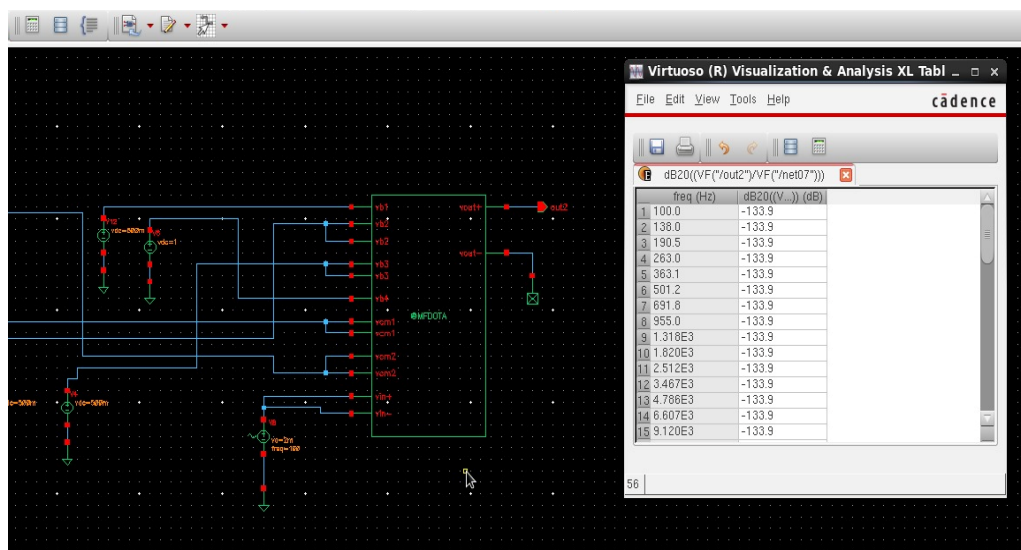


Fig11: common mode gain

The common mode rejection ratio (CMRR) is commonly applied to measure the common mode gain of an OTA. It is expressed as the differential mode gain over common mode gain. The better the rejection of the common mode signals, the greater the CMRR.

$$\text{CMRR} = \frac{\text{Differential gain}}{\text{Common mode gain}} \dots\dots\dots (8)$$

CMRR expressed in Decibels:

$$\text{CMRR (dB)} = \text{differential gain(dB)} - \text{Common mode gain(dB)} \dots\dots\dots (9)$$

$$\text{CMRR (dB)} = 57.66\text{dB} - (-133.9\text{dB})$$

$$\text{CMRR (dB)} = 191.56\text{dB}$$

V. LAYOUT GENERATION

Layout means arranging components and interconnections on a PCB or IC to satisfy electrical, mechanical, and reliability requirements. An optimum layout maximizes performance by keeping noise and signal interference at low levels, but poor layouts are responsible for signal distortion and electromagnetic interference. Layout involves component positioning and routing signals with specialized tools, taking thermal management, signal integrity, and substrate material into account.

After completion layouts are tested and simulated for performance and functionality, such as signal integrity, thermal analysis, and EMC. For the multipath differential OTA, the layout was designed using and DSCH &

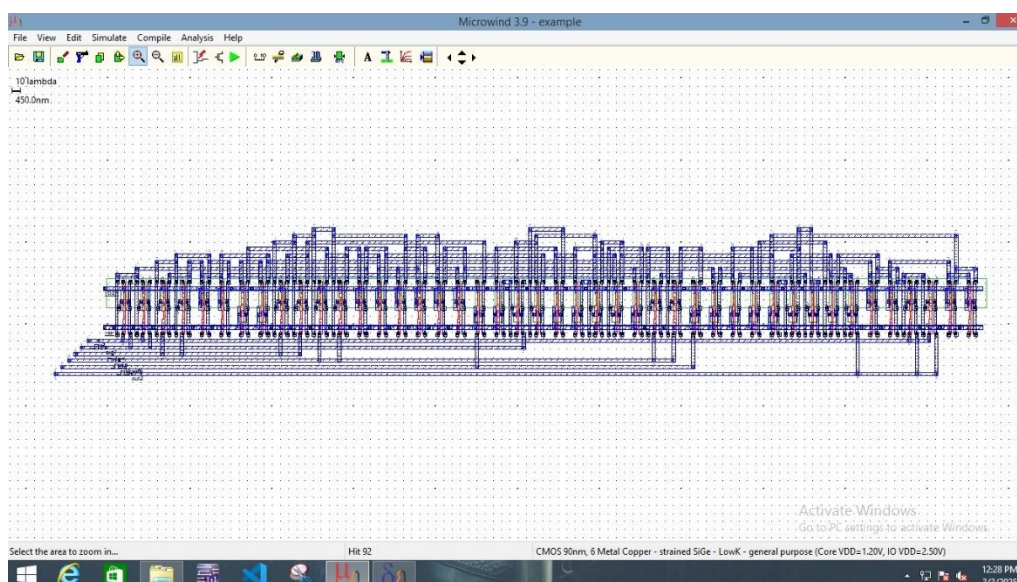


Fig 13: generated Layout

microwind tools with 90nm technology. The circuit was initially simulated in DSCH with W/L ratios, validated, and saved as a Verilog file. The layout was then created in microwind by compiling and running the Verilog file to ensure accurate representation for further verification.

VI. COMPARISION OF RESULTS

The Multipath Differential OTA is the best performer among the four 90nm OTA designs shown in the table, and it particularly outperforms the others in three key parameters. It has the highest gain of 57.66 dB, which means that it has the best capability to amplify weak input signals compared to the others.

Table 1: Comparison of results

Parameter	Two stage OTA [5]	Current mirror symmetrical OTA [4]	Cascaded current mirror symmetrical OTA [2]	Multipath differential OTA
Technology	90nm	90nm	90nm	90nm
Gain(dB)	>10	45	53.113	57.66
Common mode gain(dB)		-157.3	-100	-133.9
CMRR(dB)		93.2	153	191.8
Power(W)	2.4mV	28.21u	16.922u	246.8u
Noise(V)		1.113u	0.26n	46.13p

In addition, its Common Mode Rejection Ratio (CMRR) is much better at 191.8 dB, which shows an excellent ability to reject unwanted common-mode noise and interference, essential for preserving signal integrity in noisy environments. Finally, the Multipath Differential OTA has the lowest noise figure of 46.13 pV, which implies that it adds very little distortion to the amplified signal due to its internal noise, and thus is well suited for high-precision applications. Although it is a power hog when compared to some of the other configurations, its huge gain, noise rejection, and signal purity advantages make it a far superior option when the top priority is high performance.

VII. CONCLUSION

This project presents the design, simulation, and analysis of a Multipath differential Operational Transconductance Amplifier (OTA) using 90nm technology within the Cadence Virtuoso analog design environment. To assess the performance of the Multipath differential OTA, a schematic was initially drawn, and a corresponding symbol was created. Subsequently, the generated symbol underwent simulation utilizing an ECG signal with a frequency of 100Hz. Various analyses including Transient Analysis, Common Mode Rejection Ratio, Noise Response, AC Response, and Total Power were conducted in the Cadence Virtuoso ADE. The MFD OTA exhibited a gain of 58dB and consumed 246.922 μ W of power from a power supply of ± 1.8 V. The simulation results were then compared with those of previous OTAs for validation. Following this, a layout was generated for the Multipath differential OTA using 90nm technology in the Cadence Virtuoso ADE. Consequently, the performance evaluation of the multipath differential OTA using 90nm technology was executed, and the results were analyzed comparatively.

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