Design and Implementation of Multipath Fully Differential OTA Implementation in LT-Spice CMOS Process.

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Abstract. In this paper, based on many input-to-output pathways, these short constructs a highly efficient completely differential transconductance amplifier. Transconductance is increased by combining certain conventional methods, such as current mirror-based routes, nonlinear tail current sources, and positive feedback. This results in a larger gain bandwidth (GBW) product and a greater dc gain. Two flipped voltage-follower (FVF) cells are used to enable adaptive biasing of all other drivers and class-AB operation as variable current sources. The slew rate (SR) performance is enhanced by the multiple input-to-output paths in the proposed topology, which act as dynamic current boosters during the slewing phase. A LT-Spice CMOS process was used to construct the circuit, yielding a silicon area of 54.5 × 30.1 µm. The experimental findings indicate a dc gain and a GBW of 173.3 MHz.

Keywords: FVF, FPGA, Multipath FVF Verilog HDL

I.INTRODUCTION

Operational Transconductance Amplifiers (OTAs) play a pivotal role in modern analog and mixed-signal integrated circuits, serving as the cornerstone for a wide array of applications ranging from signal processing to control systems. Among the various OTA architectures, the Multipath Fully Differential OTA stands out for its advanced design principles and superior performance characteristics.

The primary function of an OTA is to convert an input voltage signal into an output current, offering high gain and bandwidth while maintaining low distortion and power consumption. Fully Differential OTAs process signals differentially, enabling robust noise rejection and improved common-mode rejection ratio (CMRR). This makes them ideal for applications requiring high-fidelity signal processing in the presence of noise and interference.

The Multipath Fully Differential OTA builds upon the foundation of traditional fully differential OTAs by incorporating a multipath architecture. This innovative design approach involves the integration of multiple signal paths within the OTA circuitry, each contributing to the overall signal processing and performance enhancement. By leveraging multiple paths, the Multipath OTA achieves significant improvements in key performance metrics such as bandwidth, linearity, and noise characteristics.

One of the key advantages of the Multipath Fully Differential OTA lies in its ability to mitigate nonlinearities and enhance signal integrity through the parallel processing of signals along different paths. This results in reduced distortion and improved dynamic range, making it well-

suited for demanding applications in communication systems, data converters, and instrumentation.

The design of a Multipath Fully Differential OTA involves careful consideration of various factors, including transistor sizing, biasing techniques, and circuit topologies. Additionally, stability and compensation mechanisms are crucial to ensuring robust operation across a wide range of operating conditions.

In this context, this project aims to explore the design, simulation, and analysis of a Multipath Fully Differential OTA. By leveraging advanced circuit design techniques and simulation tools, we seek to understand the intricacies of multipath architectures and evaluate their impact on OTA performance. Through comprehensive analysis and experimentation, we aim to elucidate the advantages and limitations of Multipath Fully Differential OTAs and contribute to the advancement of analog circuit design methodologies.

Overall, the Multipath Fully Differential OTA represents a significant advancement in OTA technology, offering unparalleled performance and versatility for demanding analog and mixed-signal applications. By delving into its design principles and performance characteristics, we aim to uncover new insights and pave the way for future innovations in integrated circuit design.

Operational transconductance amplifiers (OTAs) are widely used in integrated circuits, including switched-capacitor circuits, voltage regulators, and biomedical circuits as a fundamental building block [1], [2]. The folded cascode (FC) structure is usually one of the best choices for low-voltage, single-stage OTA, where high dc gain and large-signal swing are required [3], [4]. Some advantages, such as lower flicker noise, lower input common-mode level, and higher nondominant poles, can also be achieved if pMOS devices are used at the input differential pair [3], [5]. However, the accuracy of mixed-mode circuits and systems, in which an OTA-based integrator or buffer is used, directly depends on the OTA's specifications. In other words, the speed and the large-signal step response are influenced by the slew rate (SR), gain bandwidth (GBW), and dc gain that affect the accuracy, for example, of an analog-to-digital converter [1].

To increase the efficiency of the conventional FC amplifier, the recycling FC (RFC) amplifier was presented in [3] and [6] achieving double GBW and dc gain. The RFC structure attracted the attention of many circuit designers to further improve its performance by employing idle devices as new drivers [7], dynamic current boosting paths [8], double recycling structure [5], transconductance enhancing method [9], [10], [11], [12], positive feedback [1], [13], and quasi-floating gate method [14]. Although all the abovementioned techniques improved the performance of the conventional amplifiers, some of them suffer from a class-A operation that limits the SR performance. Indeed, a constant tail current source delivers the same current for both small- and large-signal operations, which certainly limits the dynamic current when a large signal is applied to the input. To remove this limitation, flipped voltage-follower (FVF)-based differential structures [15], [16] were used [17], [18] to provide a variable tail current source by which the dynamic current can be increased, depending on the input signal amplitude.

It also provided a situation under which the circuit was adaptively biased that caused a class-AB operation during slewing phase. Nonetheless, these techniques limit the frequency response of the OTA, because of more input-to-output paths, resulting in a lower phase margin. Therefore, designing and implementing high-gain and high-speed OTAs in CMOS technology with low expenses in power consumption and die area are still a challenge that circuit designers are dealing with.

In this brief, two FVF cells are used as two nonlinear tail current sources with the capability of increasing the dynamic currents under large-signal operation, causing a high SR performance. 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 reincrease the transconductance. Employing these techniques causes a class-AB operation that 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 abovementioned techniques not only enhances the circuit performance but also results in very low expenses in power consumption and die area; thus, such a combination could be one of the best choices among other efficient structures.

II. PROPOSED METHOD AND ITS METHODOLOGY

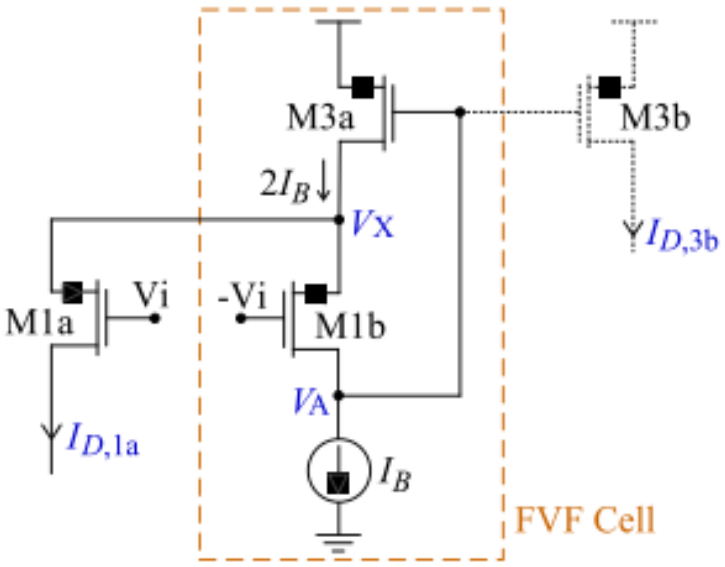

Fig. 1. FVF-based differential structure.

Fig. 1 shows the FVF-based differential structure that was realized by adding the transistor M1a to the FVF cell composed of M1b and M3a . Due to the low output resistance of the FVF circuit and improved accuracy, we can assume that the ac voltage at node X (Vx) is approximately equal to Vi , (Vi ≈ VX). Therefore, a kind of differential input signal (+Vi and −Vi) is applied to the gate and source terminals of M1a, causing two times enhancement in the transconductance for a short-circuit current at the drain of M1a, (ID,1a/Vi) ≈ −2gm,1a. Another advantage of this structure could be its unity voltage gain between the input and node A (VA/Vi ≈ −2gm,1a/gm,3a). Indeed, if both M1a and M1b are biased by the same current IB, the input signal appears at node A with a gain of 1; thus, it can easily be mirrored to the output load, through M3b, for further transconductance enhancement, (ID,3b/Vi) ≈ −gm,3b. Regarding large-signal operation, the FVF cell plays the role of a variable tail current source for both transistors

M1a and M3b such that when the amplitude of the input signal is increased, the output currents ID,1a and ID,3b are nonlinearly increased.

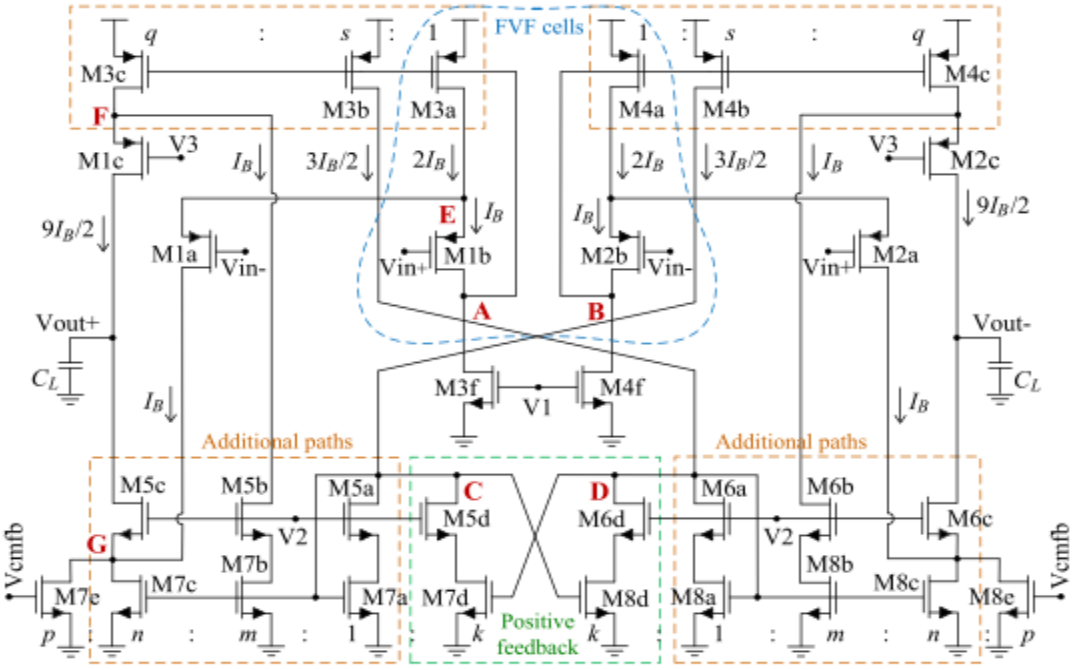

Fig2. Proposed multipath fully differential amplifier.

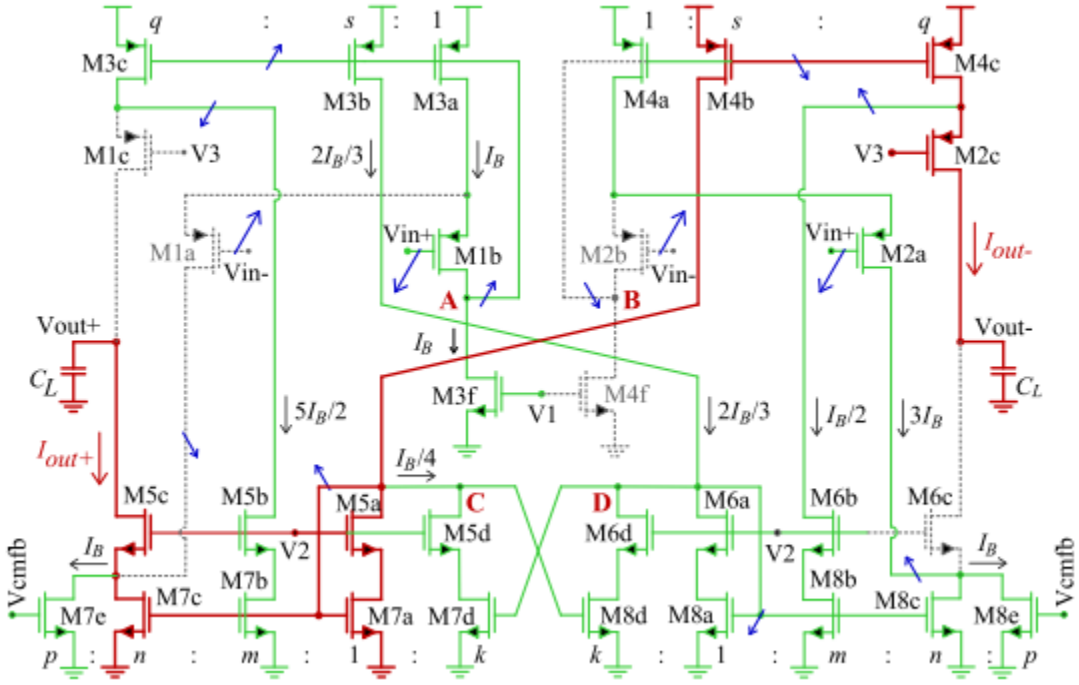

Fig3. Large-signal behavior of the proposed OTA.

A Flipped Voltage Follower (FVF)-based differential structure refers to a type of analog circuit configuration used in electronic design, often in the context of operational amplifiers (op-amps) or other analog circuits. The flipped voltage follower is a variation of the traditional voltage follower circuit. Let's explore the concept of Flipped Voltage Follower (FVF), In a flipped voltage follower, the inverting and non-inverting inputs are swapped compared to the traditional voltage follower. This configuration is sometimes used to achieve specific circuit characteristics. The flipped voltage follower has its output connected to the non-inverting input and the input signal connected to the inverting input. The purpose of this configuration can vary, and it might be employed to achieve certain performance or design objectives. For instance, it may be used in differential amplifiers or other circuits where the relationship between the inputs and outputs needs to be carefully controlled. Differential Structure is the term "differential structure" indicates that the circuit is designed to process the difference between two input signals. In a differential amplifier or a differential circuit, the output is related to the difference between two input signals. So, a "flipped voltage-follower-based differential structure" could refer to a circuit where flipped voltage followers are utilized in a differential configuration. The specific application and design goals would determine the advantages and use cases of such a structure.

OTA stands for Operational Transconductance Amplifier. It is a type of analog integrated circuit (IC) that operates as a voltage-controlled current source or transconductance amplifier. OTAs are commonly used in various analog signal processing applications, including filters, oscillators, and voltage-controlled amplifiers.

Key characteristics and features of OTAs includes to Voltage-to-Current Conversion of an OTA converts an input voltage into an output current. The transconductance (gm) parameter represents the relationship between the input voltage and the output current. High Linearity of

OTAs are designed to provide high linearity in their operation, making them suitable for applications where precise control of the transconductance is essential. Voltage-Controlled Amplification is in the transconductance of an OTA can be controlled by varying an external bias voltage. This feature allows for voltage-controlled amplification, making OTAs versatile in applications that require variable gain.Low Distortion of an OTAs are designed to minimize distortion in their output signals, ensuring that the amplified signal remains faithful to the input. Differential Inputs are the Many OTAs have differential inputs, allowing them to process the difference between two input voltages. This makes them suitable for differential amplifier configurations. Frequency Compensation of OTAs often include circuitry for frequency compensation to ensure stable operation across a range of frequencies.

Fig. 2(a) shows the structure of the proposed OTA in which transistors M1a and M2a are basic drivers that can be found in all FC-based topologies. Unlike a conventional OTA, transistors M1a and M2a are biased by two nonlinear current sources, created by FVF cells, thus providing two FVF-based differential structures. Note that since the input signal is applied to both gate and source terminals of the basic drivers M1a and M2a, achieving a double transconductance is expected. In addition, the idle pMOS load transistors, M3c and M4c, are adaptively driven by M3a and M4a, respectively. Consequently, M3c and M4c operate as additional drivers, further increasing the small-signal transconductance of the OTA. In a similar way, two additional paths are created by M3b and M4b to drive the idle nMOS load transistors M7c and M8c too. To achieve this goal, two nMOS diode-connected topologies, M7a and M8a, are employed to form two current mirrors, M7a:M7c and M8a:M8c. Thus, the input signal is also applied to the gate terminals of M7c and M8c as two new drivers resulting in further transconductance enhancement.

Due to the application of partial positive feedback circuit, created by cross-coupled transistors M7d and M8d, another enhancement in the transconductance is achieved. The positive feedback increases the impedance seen from nodes C and D, thus increasing the amplitude of ac signal at these nodes, and consequently increasing the small signal transconductance of the OTA. Such an enhancement can efficiently be reused by adding another path through M7b and M8b, which causes the fifth transconductance enhancement. Thus, considering all the above effects, the small signal transconductance of the proposed OTA is expressed by

$$G_m \approx 2g_{m,1a} + g_{m,3c} + \frac{g_{m,3b}}{g_{m,7a} - g_{m,7d}}\left(g_{m,7c} + g_{m,7b}\right)$$

where gm,i represents the transconductance of transistor Mi. Assuming the same overdrive voltage, Vod, for all transistors, it can be considered that gm,3a = 2(gm,1a), gm,3c = q(gm,3a), gm,3b = s(gm,3a), gm,7d = k(gm,7a), gm,3b = (1 + k)gm,7a, gm,7b = m(gm,7a), and gm,7c = n(gm,7a).

III. RESULTS AND ANALYSIS DISCUSSION

FVF Diff Output waveforms

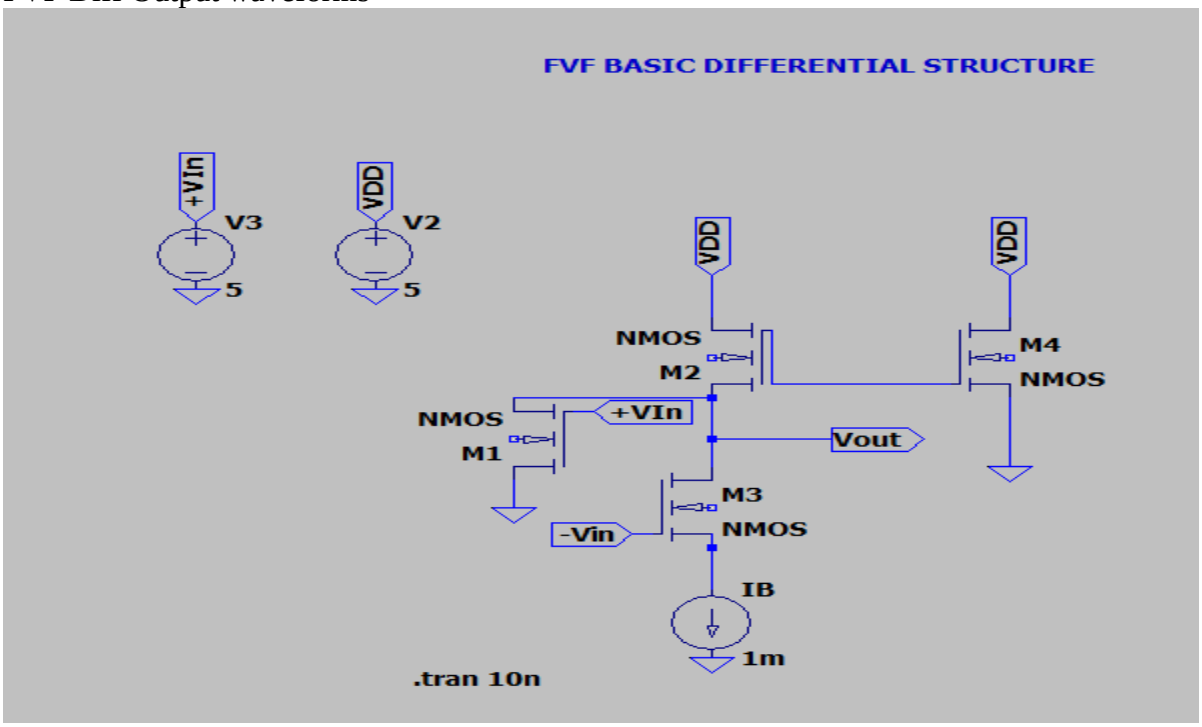

Fig1.FVF LT Spice simulated circuit diagram.

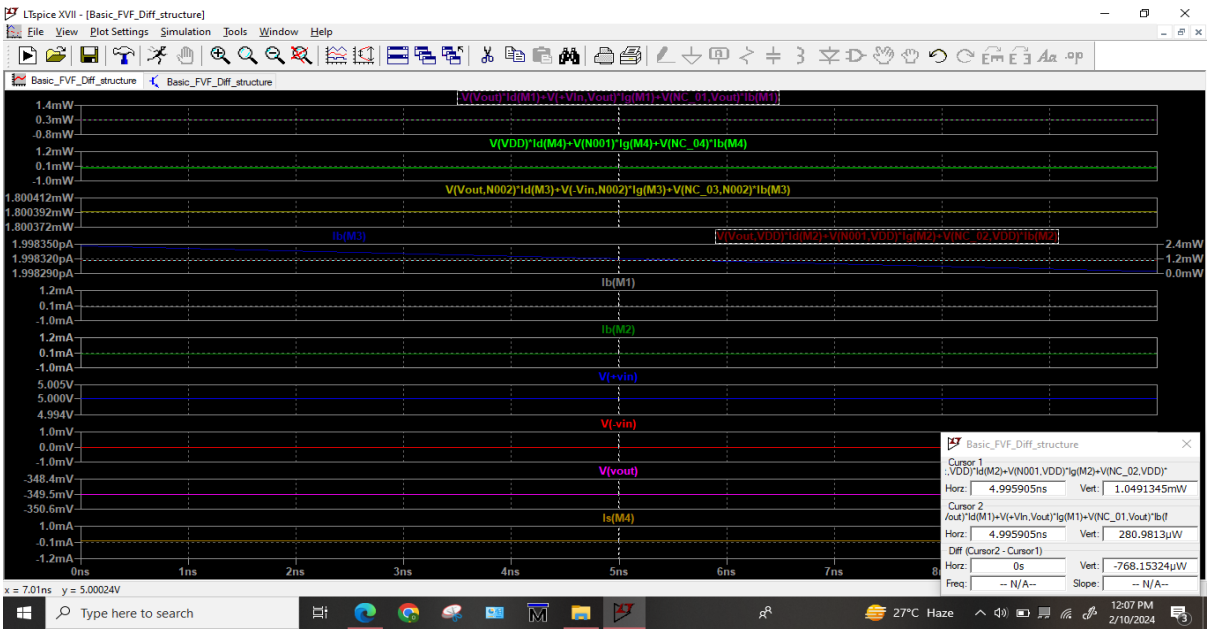

Fig2.FVF LT Spice simulated output diagram.

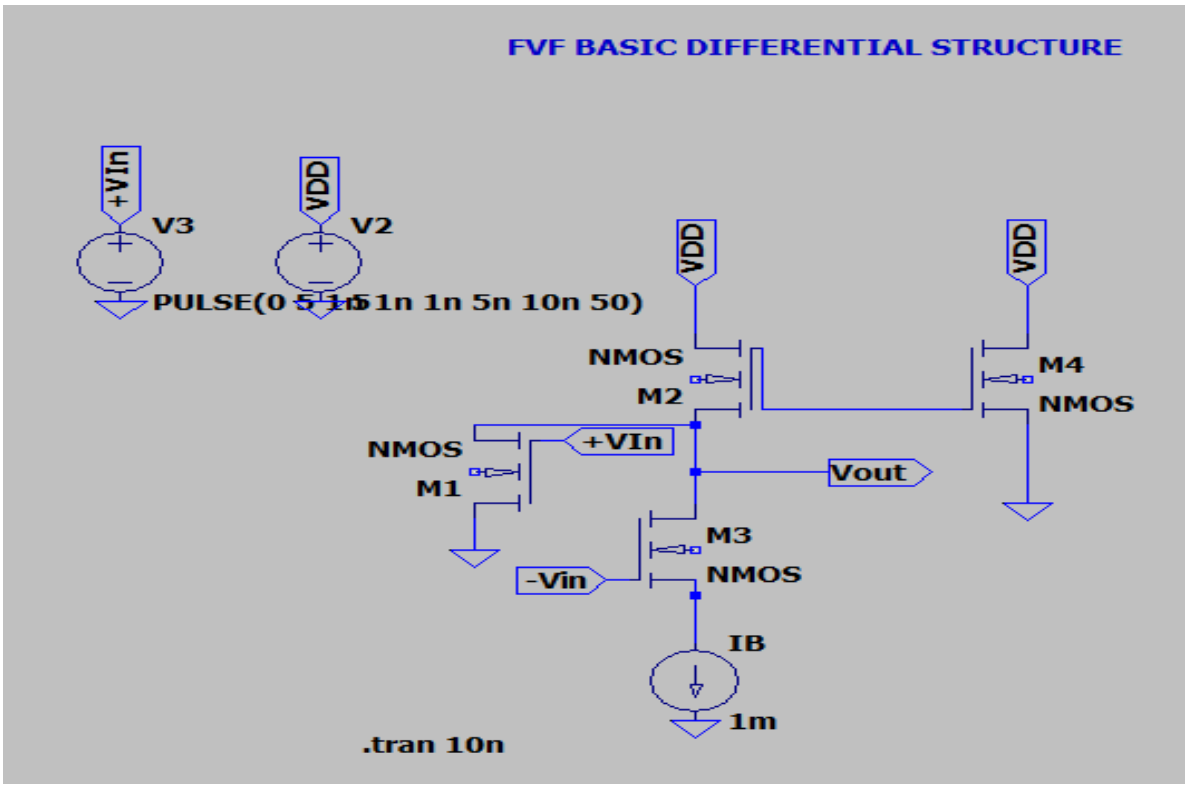

Fig3.FVF LT Spice simulated with pulsed circuit diagram.

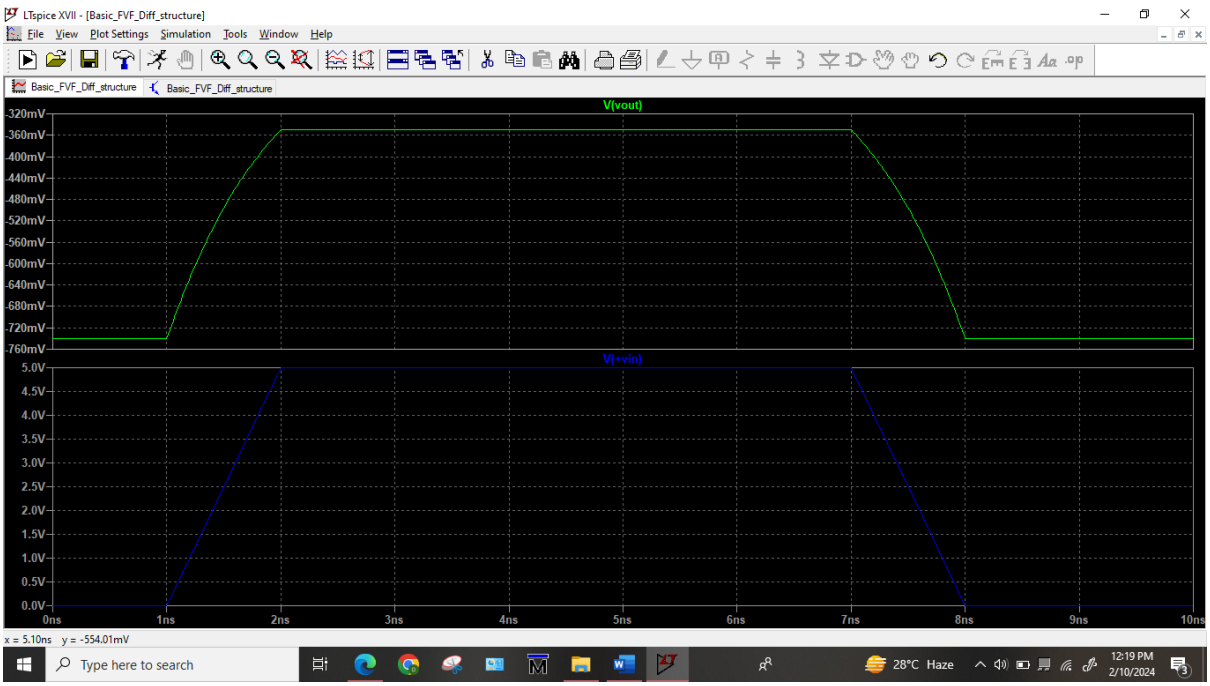

Fig4.FVF LT Spice simulated with pulsed output diagram.

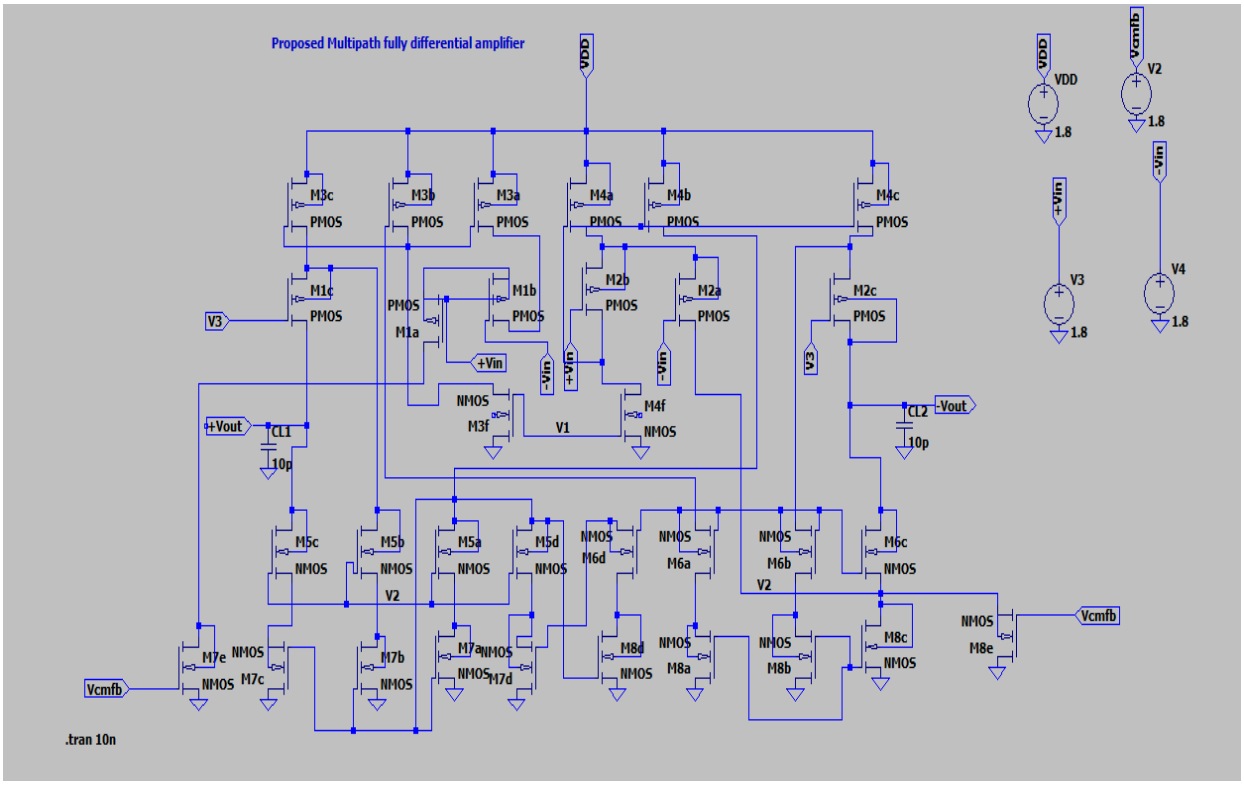

Fig5. Proposed multipath fully differential amplifier large signal OTA LT Spice simulated with circuit diagram.

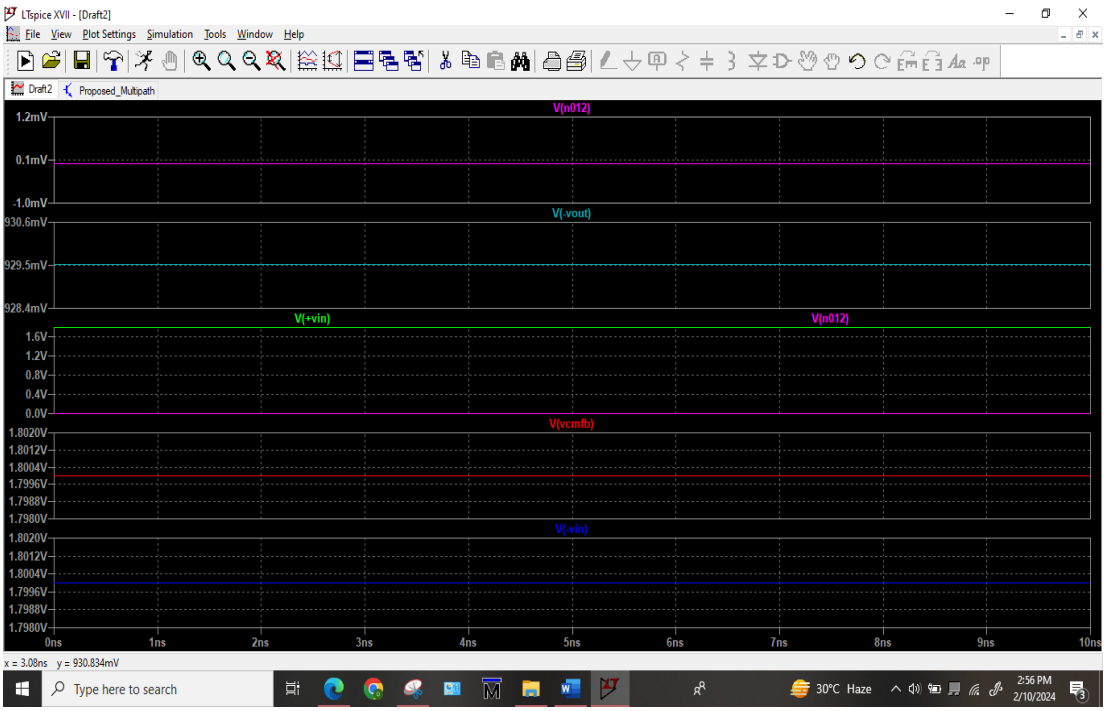

Fig6. Proposed multipath fully differential amplifier large signal OTA LT Spice simulated with output diagram.

CONCLUSION

In conclusion, Operational Transconductance Amplifiers (OTAs) are indispensable components in analog and mixed-signal circuit design, offering versatility, high gain, and low distortion characteristics. a fully differential OTA with improved transconductance and SR was proposed. The circuit was designed on LT Spice simulators using CMOS implementation process.

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