Low-Voltage Multi-input High Trans-conductance Amplifier using Flipped Voltage Follower and its application in High Pass Filter

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***Abstract*—In this paper, a multi-input transconductance amplifier using Fully Differential Flipped Voltage Follower (FDFVF) has been proposed. The proposed circuit works at low supply voltage and produces large output current while using minimum number of active and passive elements. FVF technique has been used due to its differential characteristics along with low voltage and low power operation. Also proposed work realizes a high pass filter. The simulations of FDFVF based amplifier and its application in high pass filter has been shown using LTspice XVII.**

Keywords—multiple-input OTA; low-voltage; operational transconductance amplifiers; flipped voltage follower; differential flipped voltage follower.

I. INTRODUCTION

Downscaling of CMOS processes has constrained analog circuits to operate with ceaselessly expanding supply voltages. This development has continuously increased the requirement of less power consumption devices. Portable electronic market has increased the need of low supply voltages and low power consumption [1][2][3]. Several techniques have been proposed to reduce supply voltage requirements. One of them is Flipped Voltage Follower (FVF).

FVFs have an advantage over conventional voltage follower because they have a unity gain and can work under less supply voltages [4]. They are helpful in implementation of linear CMOS transconductors. Differential FVF structures are used to build low power, low voltage Class AB stages [5].

Multiple Input-Operational Transconductance Amplifier (MIOTA) has similar structures like OTA with the difference that it has n-number of voltage inputs which are converted into single output current. Therefore, there is increase in the transconductance.

In this paper, the research work carried out is organized as follows: Section II discusses FVF and different structures of FVF and their DC characteristics in order to show that FVF has unity gain, can be used at low supply voltages and has less power consumption. Section III discusses basics of Operational transconductance amplifier (OTA) and MIOTA. Section IV shows the proposed work in FDFVF transconductor that uses multiple inputs and gives the advantage of large output current. Also, their use in MISO high pass filter. Section V shows the simulation results. Section VI concludes the work.

II. LOW VOLTAGE STRUCTURES

A. Flipped Voltage Follower:

A common drain amplifier (shown in Fig. 1) also known as source follower or voltage buffer is one of the basic building blocks of the analog systems. There is a constant current source I_x biasing on the source terminal of M1 transistor which keeps the gate to source voltage constant. If the body effect is neglected, output follows the input voltage with a dc shift of constant V_{SGM1} as given by Eq. 1. When the load current changes, the current through transistor M1 changes and thus V_{SGM1} is not constant, therefore for resistive and capacitive (at high frequency) loads output of the source follower does not follow input and hence voltage gain of the circuit is less than unity.

$$V_{out} = V_{in} + V_{SGM1} \tag{1}$$

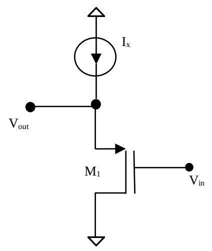

Fig. 1. Common drain amplifier

The Flipped Voltage Follower (FVF) overcomes this drawback. This circuit in Fig. 2(a) or 2(b) is an enhanced version of conventional voltage follower.

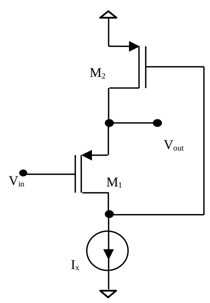

Fig. 2(a). PMOS FVF

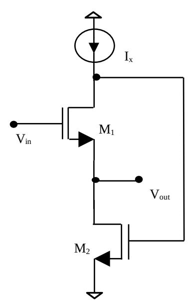

Fig. 2(b). NMOS FVF

It has an extra transistor M_2 connected in series-shunt feedback with the input transistor M_1 to keep the current through M_1 constant, independent of the output load [4]. Any deviation in the output current due to load is absorbed by the MOSFET in feedback path (M_2). Keeping V_{SGM1} constant and body effect and the short channel effects are neglected, voltage gain is unity.

B. *Differential Flipped Voltage Follower:*

A Differential structure can be built by adding an extra transistor M_3 at node B in basic FVF cell, shown in Fig. 3(a) and 3(b). Node B is the output of FVF cell and has low output impedance because of which if there are large current variations at the output, the voltage at output remains approximately constant [4]. Assuming same aspect ratios of M_1 and M_3 and under quiescent conditions (V_1=V_3), I_{DM3}=I_{DM1}=I_X. If a non-zero differential input i.e. V_1-V_3 is given, current variations in M_3 increases exponentially (obeying MOS square law). The maximum output current is much greater than the quiescent current. The DC characteristics are shown in Fig. 4.

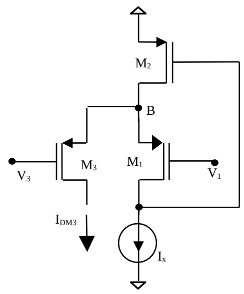

Fig. 3(a). DFVF PMOS

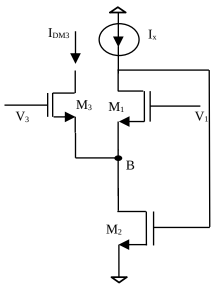

Fig. 3(b). DFVF NMOS

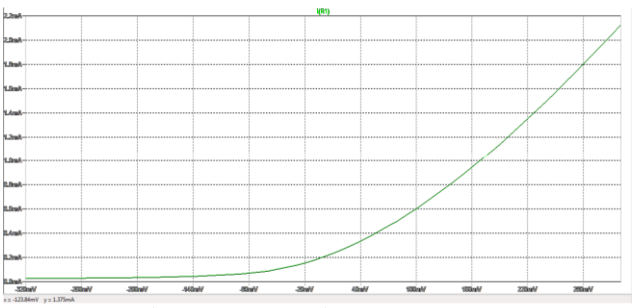
Fig. 4. DC Transfer Characteristics of PMOS DFVF

Important applications of DFVF are:

a) It can provide output as both current (I_{DM3} which can be copied through current mirrors) and voltage.
b) Differential class AB circuits can be derived [4].
c) It reduces number of poles and zeros, thus reduces noise.
d) It is operated at low supply voltage.

C. *Fully Differential Flipped Voltage Follower:*

Differential FVF shows one side of the output current, Fully Differential FVF (shown in Fig. 5(a) and 5(b)) has two DFVFs connected such that the output gives a fully differential behavior, at any value of V_1-V_3 there are two values of current. The output current produced is much larger than the biasing current (I_X) thus it shows class AB behavior.

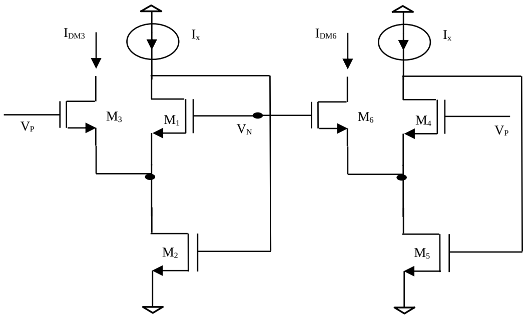

Fig. 5(a). NMOS based Fully Differential Flip Voltage Follower (FDFVF)

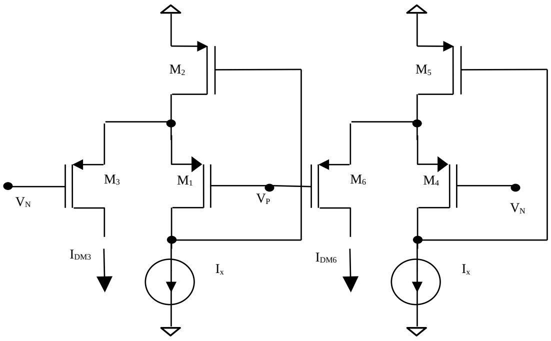

Fig. 5(b): PMOS based Fully Differential Flip Voltage Follower (FDFVF)

Output currents generated (I_{DM3} and I_{DM6}) are proportion to the differential input voltages at transistor M_1 and M_4. It has large CMRR. Under quiescent condition when V_1=V_3 and same dimensions of transistors M_1(M_3) and M_4(M_6) which are making differential pair, then I_{DM3}=I_{DM1}=I_X [6]. DC characteristic of FD-FVF is shown in Fig. 6.

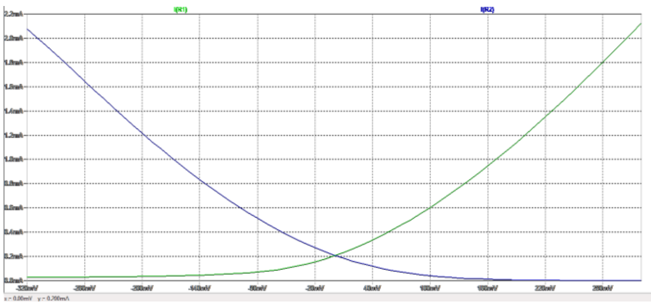
Fig. 6. DC Transfer Characteristics of PMOS FDFVF

III. OTA AND MIOTA

OTA is a Voltage Controlled Current Source (VCCS) which accepts differential input voltage. The schematic symbol of OTA is shown in Fig. 7.

An ideal transfer characteristic of OTA is expressed as:

$$I_{out} = g_m(V_p - V_n) \quad (2)$$

where, V_p is the positive input voltage, V_n is the negative input voltage and g_m is transconductance. g_m of an OTA can be changed by varying its biasing current (I_B). Thereby, OTA provides the flexibility of electronic tuning. OTAs given in

[7][8][9] has major constraint that biasing current limits the output current and hence, circuit performance.

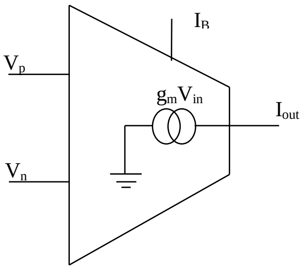

Fig. 7. OTA

Generally, an OTA has 2-input terminals. However, it can be designed with more number of input terminals, termed as MIOTA [10][11]. Symbolic structure of MIOTA is shown in Fig. 8. MIOTA is structurally similar to OTA with the difference that it has n-number of differential stages cascaded in parallel. MIOTA can convert more number of voltage inputs into a single output current, given by the expression:

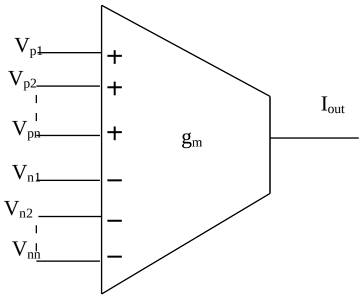

Fig. 8. MIOTA

$$I_{out}=g_m\left([V_{p1}+V_{p2}+V_{pn}]-[V_{n1}+V_{n2}+V_{nn}]\right) \quad (3)$$

where, g_m is transconductance of MIOTA. The output current and thereby g_m of MIOTA are greater than 2-input OTA. Moreover, it helps in designing large circuits with lesser number of components.

IV. Proposed work

In this section, FDFVF based multiple input amplifier has been designed and proposed. It has additional mosfets in parallel with M_3 and M_4 whose sources are connected together at low impedance node. This circuit uses low voltage supply and has large CMRR.

$$V_{DD}^{min} = |V_{TP}| + 2|V_{DSAT}| \quad (4)$$

where, V_{TP} is the threshold voltage and V_{DSAT} is the minimum drain to source voltage which is required to maintain a transistor in saturation. Fig. 9 shows that the low voltage operation is maintained in proposed circuit while it provides high transconductance and multi-input facility.
The drain of mosfets M_3 (M_4), M_7 (M_8), M_9 (M_{10}) and so on are connected together to produce the output current.

$$I_{out} = I_{DM3} + I_{DM7} + I_{DM9} + \cdots I_{DMn} \quad (5)$$

If mosfets M_3, M_7… M_n are matched, then transconductance of proposed circuit (g_{mp}) can be given as:

$$g_{mp} = n * g_m \quad (6)$$

where, g_m represents the transconductance of conventional FDFVF.

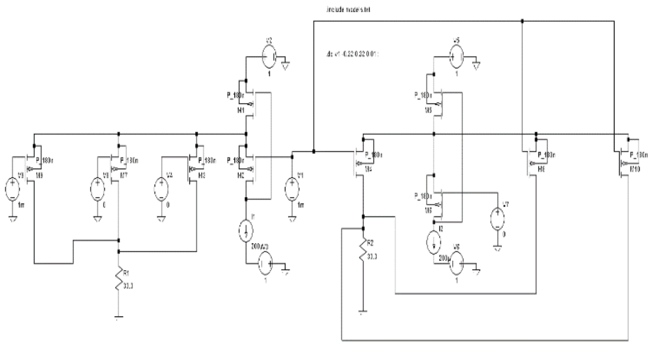

Fig. 9. Proposed FDFVF OTA

A voltage mode multi-input single output filter [12] is realized by using the proposed FDFVF OTA. Symbolic representation of the circuit is shown in Fig. 10. The MISO filter utilizes one capacitor and one multi-input FDFVF OTA. It works as a High Pass Filter.

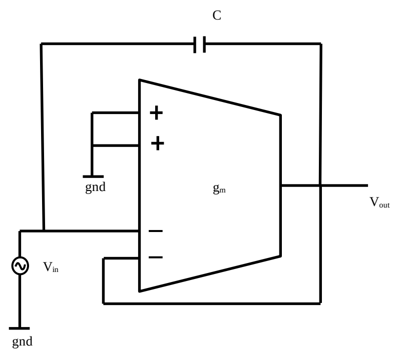

Fig. 10. High Pass Filter [12]

The High Pass filter structure based on FDFVF is shown in Fig. 11 with one extra mosfet on each side of conventional FDFVF.

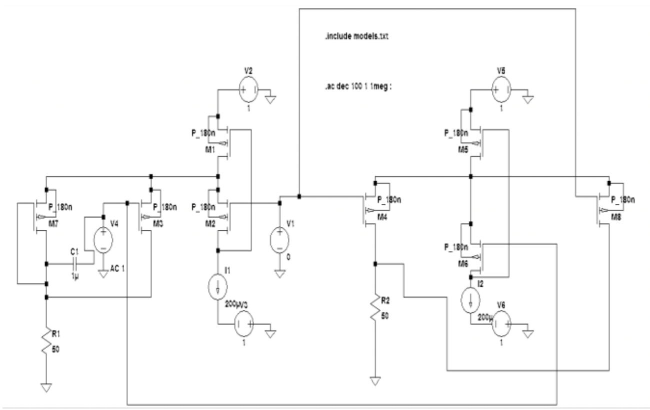

Fig. 11. MISO high pass filter using proposed FDFVF transconductor

V. SIMULATION RESULTS

The simulations of FDFVF based amplifier and its application in high pass filter has been done LTspice XVII, Table 1 summarizes design parameters of the circuits shown in Fig. 9 and Fig. 11.

TABLE I. VALUE OF COMPONENTS IN MISO FILTER IN FIG. 11.

Components	
Name	*Value*
M_2, M_3, M_7, M_4, M_6, M_8	400u/1u
M_1, M_5	200u/1u
I_X	200u
V_{DD}, V_{SS}	+1, -1
C	1u, 10n, 100n

The proposed circuits are simulated at supply voltage of ±1V. A load of 33.3Ω is used to obtain the output current in the circuit shown in Fig. 9. The simulation results of proposed fully differential structure with two additional MOSFETs on both sides have been carried out in LTspice. DC response is shown in Fig. 12.

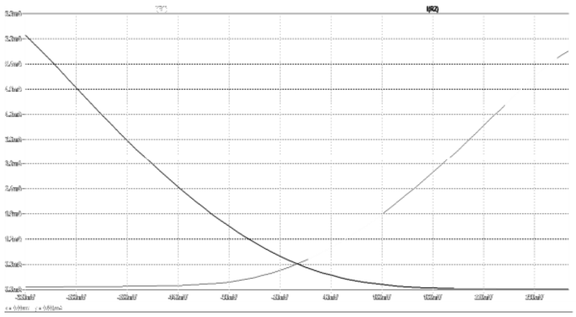

Fig. 12. DC response of Proposed FDFVF OTA

For comparison purpose the similar DC characteristic for FDFVF is shown in Fig. 13. It is observed that with increase in number of inputs, output current and thereby g_m increases proportionally.

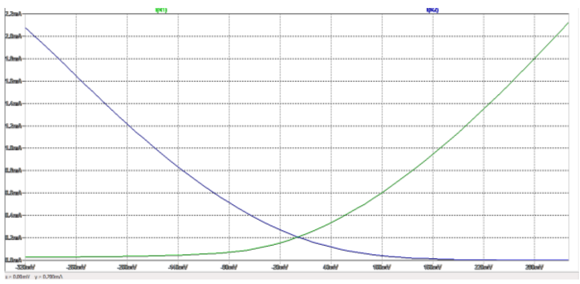

Fig. 13. DC response of FDFVF

Increase in two transistors on each side, triples the output current as finally there are three transistors on each side working. Therefore, $g_m' = 3*g_m$. At quiescent condition $V_p - V_n = 0$, output current is equal to the biasing current I_X=200uA.

Gain Response and Phase response of High-Pass Filter using proposed FDFVF transconductor (Fig. 11) are shown in Fig. 14 and Fig. 15 respectively. This MISO filter is operated at ±1V and has a cut-off frequency of 3kHz.

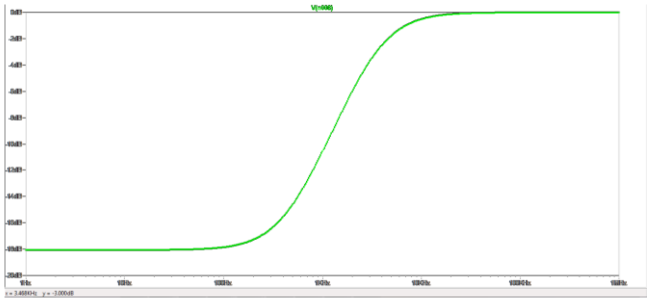

Fig. 14. Gain Response of Proposed MISO High Pass Filter

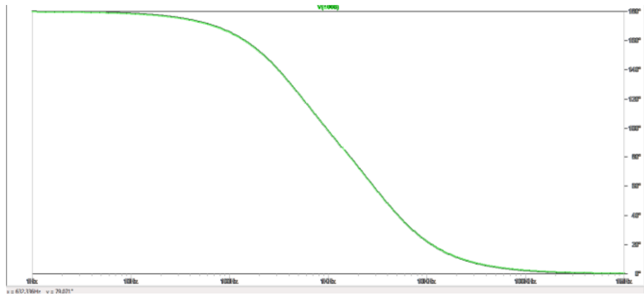

Fig. 15. Phase Response of Proposed MISO High Pass Filter

The High pass filter has gain in the frequency from cut-off frequency (w_c) to infinity. Any input having frequency below w_c is rejected and value above it passes unaffected.

The cut-off frequency of the filter is given by equation,

$$f_c = \frac{1}{2\pi RC} \qquad (7)$$

Parametric analysis showing the change in cut-off frequency of the circuit (Fig. 11) is shown in Fig. 16. If the Capacitor value is reduced the cut-off frequency of the filter increases.

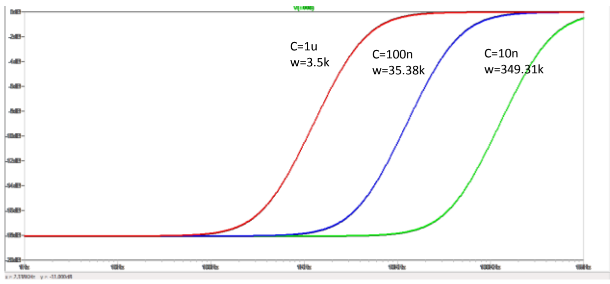

Fig. 16. Parametric analysis showing the change in cut-off frequency of the proposed filter with the change in Capacitor

VI. CONCLUSION AND FUTURE WORK

In this paper a multi-input transconductance amplifier has been proposed and a high pass filter using the proposed transconductor has been designed. The proposed circuit utilizes the advantage offered by FVF and provides flexibility of providing multiple inputs. This FVF based multiple input offers higher output current and transconductance as compared to conventional FVF structure. In this work results were demonstrated on a circuit with one or two additional input node though further improvements can be achieved by increasing the number of inputs. Also, MISO high pass filter has been realized which has one MIOTA and one capacitor. Its cut-off frequency varies with the change in value of capacitor.

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