

Design and Analysis of High Gain CMOS Telescopic OTA in 180nm Technology for Biomedical and RF Applications

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ABSTRACT

The Operational Transconductance Amplifier (OTA) is the block with the highest power consumption in analog integrated circuits in many applications. Low power consumption is becoming more important in miniature devices, so it is a challenge to design a low power OTA. There is a trade-off between speed, gain and power for an OTA design since these parameters are contradicting each other. There are mainly four different types of OTAs: two stage OTAs, folded-cascode OTAs, telescopic OTAs, flavours of Gain boosted OTAs. The telescopic transconductance amplifier consumes less power compared with the other three transconductance amplifiers, so it is widely used in low power consumption applications. It has also high speed characteristics compared to other three topologies. In this paper Telescopic OTA is designed for 180nm Technology using cadence tool. This designed Telescopic OTA achieved gain 184.4dB, Phase Margin 168.85 degrees, UGB 10GHz which are the basic performance parameters of an OTA.

KEYWORDS

Operational Trans-conductance Amplifier (OTA), Telescopic OTA, Gain, Phase margin, UGB.

1. INTRODUCTION

The OTA is basic building block usually used in designing many analog circuits such as data converters and Gm-C filters. Performance of Gm-C filters is related and based on to the OTA's performance. The OTA is a Transconductance device where the input voltage controls the output current, it means that OTA is a voltage controlled current source device whereas the op-amps are voltage controlled voltage source electronic devices. An OTA is basically an op-amp without output buffer, so it can only drive loads.

An operational trans-conductance amplifier (OTA) is a voltage input current output amplifier. The input voltage V_{in} and the output current I_o are related to each other by a constant of proportionality and the constant of proportionality is the transconductance "gm" of the amplifier.

$$I_o = gm V_{in} \quad (1)$$

Where gm= Transconductance of OTA.

V_{in} = Differential input voltage

Figure 1 shows how to represent OTA symbolically.

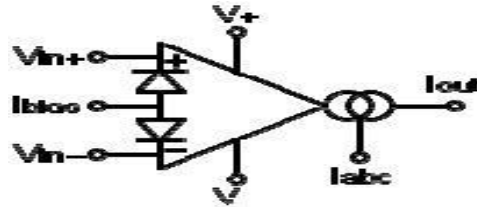


Figure 1: OTA symbol

The transconductance g_m of the OTA can be obtained by varying the value of the external controlling current I_C .

$$g_m = KI_C \quad (2)$$

Where K = suitable constant of proportionality

Substituting equation (1) into equation (2), we get,

$$I_o = KV_{in}I_C \quad (3)$$

Equation (3) depicts that output current is proportional to the product of V_{in} and I_C . In general OTA consists of a differential transistor pair with a current mirror circuit acting as a load. As OTA operates on the principal of processing current rather than voltage, it is an inherently robust device. As g_m can be controlled by changing the control current I_C , the OTAs are suitable for electronically programmable functions.

In this paper Telescopic OTA is designed to satisfy High Gain.

2. CIRCUIT IMPLEMENTATION

2.1 Design of Telescopic Operational Transconductance amplifier

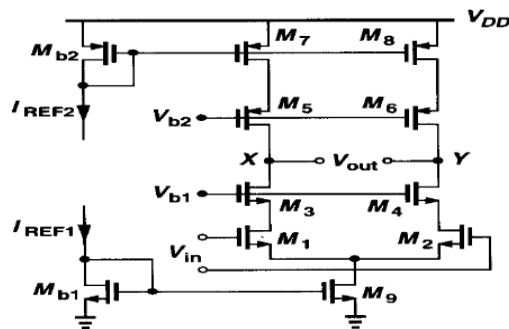


Figure 2: Telescopic OTA

Telescopic OTA shown in Figure 2 comprises of 11 MOSFETS out of which Mb1,M9,M1,M2,M3,M4 are NMOS and Mb2,M5,M6,M7,M8 are PMOS.

It consists of M1; M2 as differential circuit. The Telescopic operational amplifier topology comprises of two current mirrors which are used to obtain the drain current of M7 and M9. Vdd is the source voltage, Vb1 and Vb2 are biasing voltages and Vin is the input voltage. Here designing part of a circuit is started from the ground level since NMOS are good current sinks and PMOS are good current source. Since PMOS channel width is greater than NMOS channel width so PMOS is connected to supply and NMOS to ground level. 3V supply is given to M9 and each cascode branch is equal to 1.5v

M9 Transistor has a capacity of 3mA. Mb1 & Mb2 has a capacity of 330µamp.

$$\text{Current (M1+M2)} = \text{M9}$$

Designing a electronics circuit can be defined as converting netlist to transistors structure. Modelling is the first step of designing. Modelling is necessarily used to convert the nonlinear circuit to linear circuit. Modelling is of two types:

- (i) Large Signal Modelling
- (ii) Small Signal Modelling

2.2 Large Signal Modelling:

It is used with the dc supply.

1. The First step in the large signal modelling is to know the transistor's operating region.
2. As the respective Operating Regions is found then fix the terminal voltages. Voltage Swing at X=1.5v & Y=1.5v
3. Then now fix the overdrive voltage
i.e. $|V_{od7}| + |v_{od5}| + v_{od3} + v_{od1} + v_{od9} = 1.5v$

Here since M9 carrying the largest current we choose approximately $V_{od9} = 0.5v$ and rest leaving 1v for four transistors.

4. M5 & M8 has low mobility so we allocate an overdrive voltage of approximately 300mv.
5. Then identify the current equation

$$I_d \propto W/L$$

The circuit diagram of Telescopic OTA comprises of 11MOSFETS out of which Mb1,M9,M1,M2,M3,M4 are NMOS and Mb2,M5,M6,M7,M8 are PMOS. Depending upon the operative region in which the respective transistor exists identify the respective Current equations.

6. Find the aspect ratios for all MOSFETS

From the libraries of the CADENCE tool we obtain the respective parameters.

FOR NMOS

- (i) $1.0\mu < \text{Gate length} \leq 20\mu$
- (ii) $10\mu < \text{Gate Width} \leq 100\mu$
- (iii) $V_{tho} = 0.45$
- (iv) $\mu_n = 0.045$
- (v) $tox = 4.0 \times 10^{-9}$

FOR PMOS

- (i) $1.0\mu < \text{Gate length} \leq 40\mu$
- (ii) $1\mu < \text{Gate Width} \leq 100\mu$

(iii) $V_{tho} = -0.44$

(iv) $\mu_p = 0.011$

(v) $t_{ox} = 4.0 \times 10^{-9}$

$E_{ox} = 3.45 \times 10^{-11}$ F/M (For both PMOS & NMOS)

FOR M9 & Mb1:

$I_D = \mu_n C_{ox} (W/L) [V_{gs} - V_{th}]^2$

We know that $C_{ox} = E_{ox}/t_{ox}$

$= 3.45 \times 10^{-11} / 4.0 \times 10^{-9}$

After substituting the respective parameters in the current equation we get

$I_D = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [0.5 - 0.45]^2$

$3 \times 10^{-3} = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [0.5 - 0.45]^2$

(W/L) = 15.41

FOR M3 & M4:

$I_D = \mu_n C_{ox} (W/L) [V_{gs} - V_{th}]^2$

We know that $C_{ox} = E_{ox}/t_{ox}$

$= 3.45 \times 10^{-11} / 4.0 \times 10^{-9}$

Substituting the respective parameters in the current equation we get

$I_D = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [200 \times 10^{-3}]^2$

$1.5 \times 10^{-3} = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [200 \times 10^{-3}]^2$

(W/L) = 19.32

FOR M5, M6, M7, M8 & Mb1:

$I_D = \mu_n C_{ox} (W/L) [V_{gs} - V_{th}]^2$

We know that $C_{ox} = E_{ox}/t_{ox}$

$= 3.45 \times 10^{-11} / 4.0 \times 10^{-9}$

Substituting the respective parameters in the current equation we get

$I_D = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [300 \times 10^{-3}]^2$

$1.5 \times 10^{-3} = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [300 \times 10^{-3}]^2$

(W/L) = 52.70

FOR M1 & M2:

$I_D = \mu_n C_{ox} (W/L) [V_{gs} - V_{th}]^2$

We know that $C_{ox} = E_{ox}/t_{ox}$

$= 3.45 \times 10^{-11} / 4.0 \times 10^{-9}$

After substituting the respective parameters in the current equation we get

$I_D = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [200 \times 10^{-3}]^2$

$1.5 \times 10^{-3} = 0.045 \times 3.45 \times 10^{-11} / 4.0 \times 10^{-9} (W/L) [200 \times 10^{-3}]^2$

(W/L) = 19.5

The respective aspect ratio values of all MOSFETs are shown in Table 1.

| MOS | Aspect ratios |
|-----|---------------|
| Mb2 | 15.41 |
| M9 | 15.41 |
| M1 | 19.5 |
| M2 | 19.5 |
| M3 | 19.32 |
| M4 | 19.32 |
| M5 | 52.70 |
| M6 | 52.70 |
| M7 | 52.70 |
| M8 | 52.70 |
| Mb2 | 52.70 |

Table 1: Aspect Ratios

3. SIMULATION RESULTS

The CMOS Telescopic operational transconductance amplifier is simulated on Cadence software for 180nmTechnology for obtaining different parameter such as UGB (Unit gain bandwidth), gain, phase margin etc. One of our main objectives is to achieve High Gain. After designing the conventional circuit and simulating, the Gain achieved is 55db. In order to improve the gain we added matching compensative passive capacitor, as a result after simulation for the capacitance of value 1pF the Gain achieved is 182.9db, for the capacitance of value 2pF the Gain achieved is 183.9db, , for the capacitance of value 3pF the Gain achieved is 184.15db.

The Simulation results are shown in Fig 3, 4, 5, 6, 7, 8, 9 and all results are summarised in Table 2.

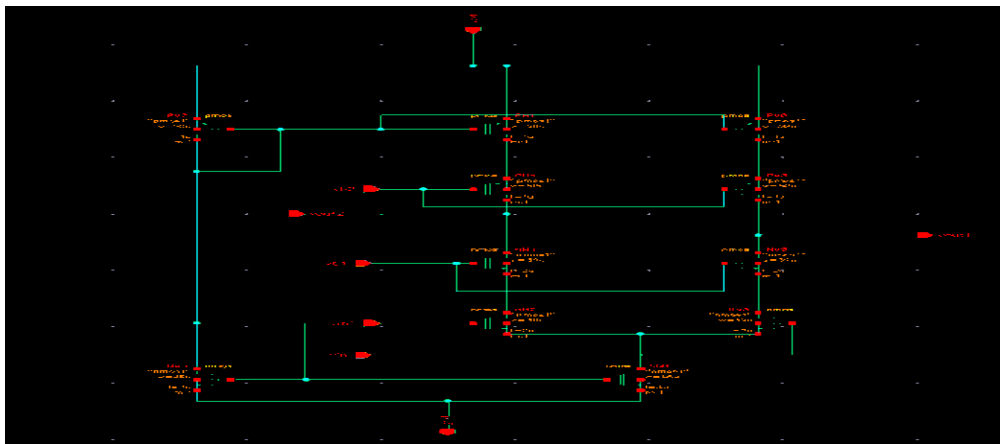


Fig 3: Telescopic OTA design in Cadence

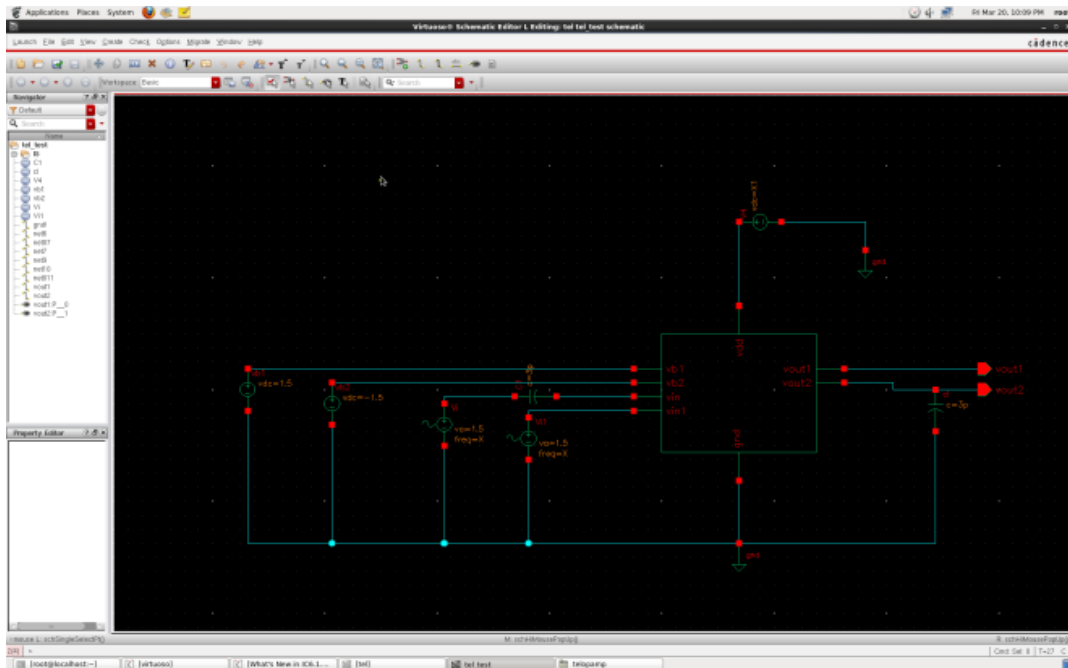


Fig 4: Symbol

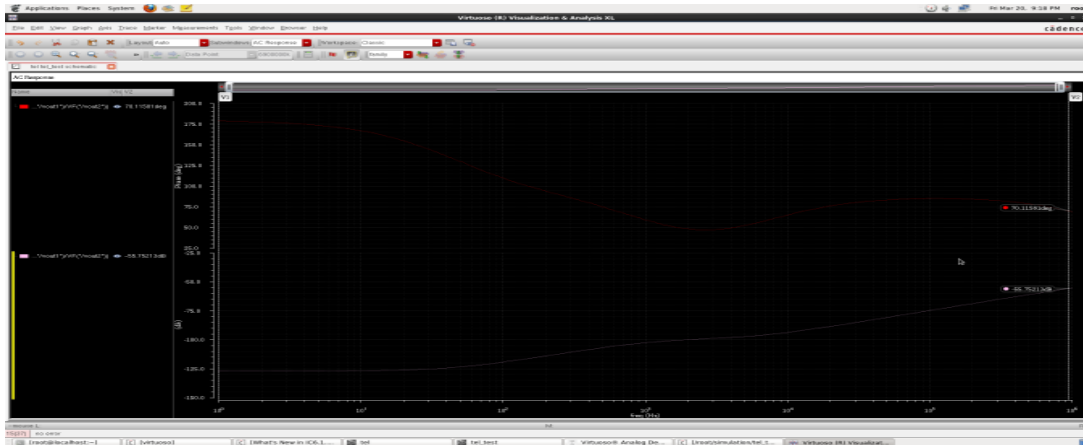


Fig 5: gain 55db without adding compensative passive Capacitor

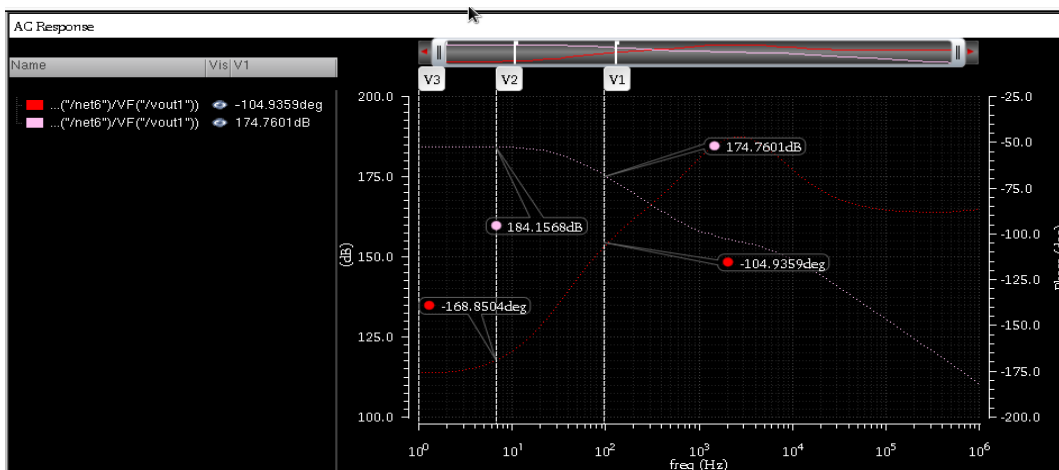


Fig 6: 184.15 db Gain at 3p F

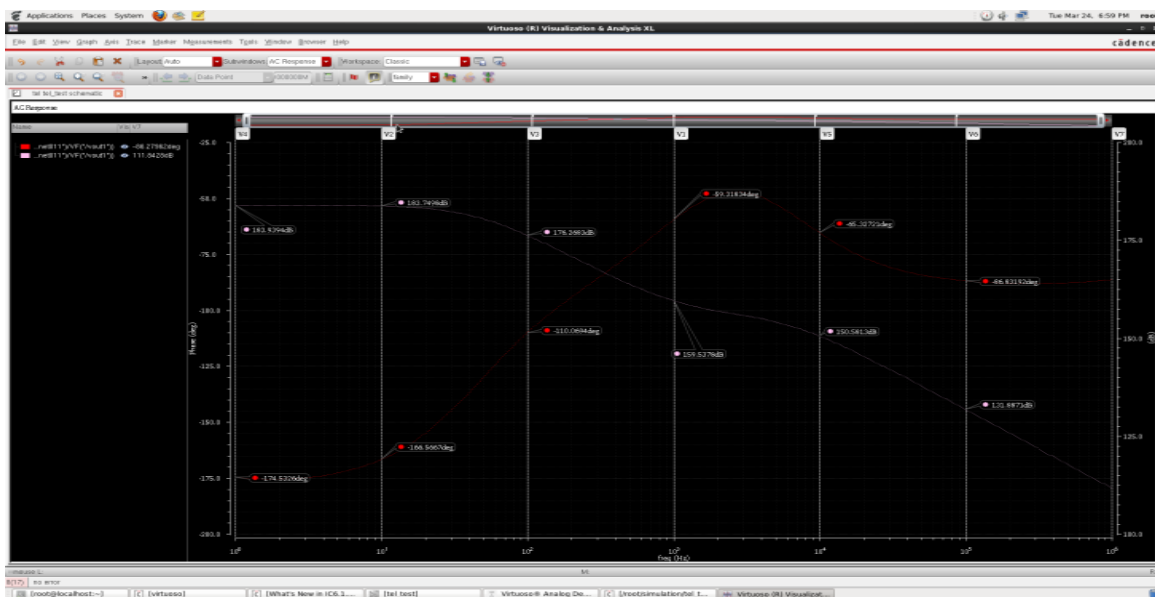


Fig 7:183.9 db Gain at 2pF

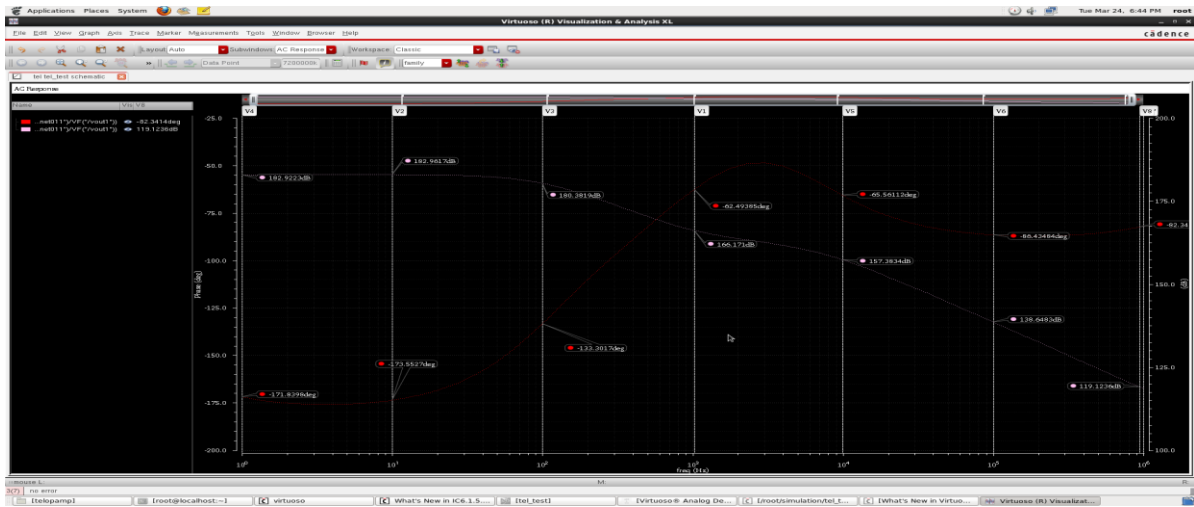


Fig 8:182.9 db Gain at 1pF

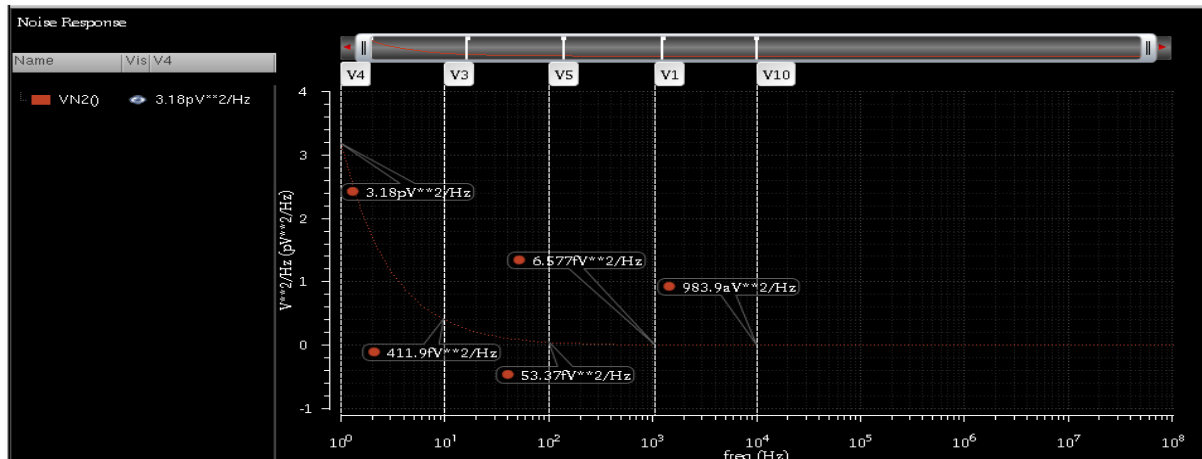


Fig 9: Noise Response

| Parameter | Result |
|----------------|--|
| Technology | 180nm |
| UGB | 10GHz |
| CL | 1pF,2pF,3pF |
| Gain | 182.9dB at 1pF 183.9dB at 2pF 184.4dB at 3pF |
| Phase Margin | 171° out of phase at 1pF 174 ° out of phase at 2pF 168.85° out of phase at 3pF |
| Supply Voltage | 3V |

Table 2: Simulation Results

4. CONCLUSION

The design and experimental results of a telescopic OTA has been presented. The proposed telescopic OTA can achieve a maximum gain of 184.15db, Phase Margin 168.25 degrees, UGB 10GHz at a power supply of 3V.

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