CHAPTER 4

A 1.2V IMPROVED OPERATIONAL AMPLIFIER FOR BIO-MEDICAL APPLICATIONS

4.1 INTRODUCTION

In recent years, there is an ever-growing demand for low-power and low-noise mixed signal integrated circuits for applications such as portable medical systems. A high level of system integration is required to implement bio-potential system with mixed signal circuits. The most commonly observed bio-potentials used for medical diagnoses are monitored non-invasively with electrodes placed on the surface of the skin (Lee et al 2006). These include the electrocardiogram or ECG which monitors heart activity; the electromyogram (EMG) which monitors muscle activity in the body; and the electroencephalogram (EEG) which monitors electrical activity in the brain. Generally, the integrated chip offers a relatively low-cost product for both ECG and EEG signals, but with high power consumption. To overcome this problem, programmable components with adjustable trade-off between noise and power dissipation are embedded in the same chip. The main source of noise is found in the first component, i.e. the preamplifier when recording the biomedical signals. Hence, a programmable operational amplifier (popamp) that acts as a preamplifier is the key component (Van Helleputte et al 2008) in the design of bio-medical system.
Programmable opamp’s are designed based on the circuit topology by Hogervorst and Huijsing (1996). The opamp’s presented by Bronskowski and Schroeder (2007), Meier auf der Heide et al (2007) uses this topology for its design and is implemented in HSPICE using 0.35µm CMOS technology with a supply voltage of 3.3V. It occupies large area and has large power consumption. So, the supply voltage of programmable opamp’s is kept around 1V to ensure less power dissipation. But, conventional analog circuit topologies will not work with this supply voltage due to the fact that, as the device sizes are scaled down, the threshold voltage of MOS transistors does not reduce, as this could cause increased leakage currents. This problem can be alleviated by using alternate MOSFETS like floating gate MOSFETs, bulk driven MOSFETs and DTMOS. A 1.2V opamp has been integrated in a 0.35 µm CMOS process (Elvi et al 2000) using floating gate input transistors in order to increase the input common mode voltage range of the opamp. Due to the capacitive division, the input signal gets attenuated resulting in poor gain, less gain bandwidth product and inferior noise properties. In bulk driven transistors (Lasanen et al 2000), the threshold voltage limitation disappears but the devices have lower transconductance value. The transconductance value lowers because of smaller control capacitance of the depletion layer, larger parasitic capacitance and higher input referred noise.

The opamp design based on dynamic threshold voltage (DTMOS) transistors is preferred for low voltage, low power bio medical applications (Achigui et al 2003). The body and the gate of this DTMOS transistor are biased at the same potential. So it is capable of processing ultra low amplitude light signals and is used to build the front end receiver part of a Near Infrared Spectro Reflectometry (NIRS) device. On the other hand, the opamp is susceptible to flicker noise (1/f), which makes it very harmful in low frequency bio medical applications because of its power spectrum and voltage
offset. So, the programming ability of the opamp should be exploited to work in both low noise mode and low power mode, if different medical applications are combined in one chip. An application of this type of opamp is used in the analog front end of a System on Chip (SoC) for biomedical signal acquisition (Kristian M et al 2007). For example, the opamp is programmed in low noise mode for sensitive electroencephalogram (EEG) recordings or low power mode for mobile electrocardiogram (ECG) applications. In contrast to conventional opamp’s, programmable opamp’s have the advantage of being adaptable to system specification.

4.2 LITERATURE SURVEY

The need for analog circuits in nanometer CMOS technology is due to the necessity to combine both digital and analog blocks into one system forming SoC (Busze et al 2010). Digital CMOS is always the preferred technology for the fabrication process due to its efficient economic costs. As a result, contemporary analog circuits must not only operate with low supply voltages, but should also be realizable in typical digital CMOS processes.

One of the most crucial building blocks in analog systems is the operational amplifier. Significant research has been carried out over recent years in the design and development of the operational amplifiers for low power applications as stated in Reid R. Harrison (2007), Stockstad and Yoshizawa (2002), Benjamin and Phillip (1995). Yet most historical topologies fell short of providing satisfactory performance below 3V power supplies. Structures in the literature typically consisted of an input stage and one or two intermediate gain stages. These gain stages had to provide high DC gain which could be achieved by using cascading. Since, opamp’s are the most critical building blocks in all analog systems, the objective of this work
is to study and analyze the theory and design of low power and low noise op amps to make it programmable.

The operational amplifier is the most important building block for use in mixed signal SoC applications (Van Helleputte et al 2008). It is an active element with high gain designed to perform a specified signal processing operation. A programmable opamp used in bio medical application amplifies the weak bio potential signal to large amplitude signal and is programmed to handle both noise and power. The basic architecture of the analog front end of a respiration monitoring system is as shown in Figure 4.1.

![Basic Architecture of Analog Front End](image)

**Figure 4.1 Basic Architecture of Analog Front End**

The respiration monitoring system is fully integrated on chip with the exception of an external capacitor for low pass filtering. The measurement principle is based on bioelectric impedance measurement on the patient’s thorax and allows the measurement of respiration concurrently with an ECG-measurement using two ECG-electrodes. The circuit is also used to detect
open leads by measuring the absolute impedance between leads. If this impedance exceeds a certain threshold, the leads are assumed to be open. The on chip oscillator generates two differential 40 kHz sine-signals, which are applied to the body electrodes through additional impedances forming a voltage divider. The applied carrier signal is modulated by a change of body impedance due to breathing of the patient.

The ECG signal and the modulated carrier are present after the preamplifiers. Because the carrier is located at 40 kHz, which is removed by the low-pass filter at the end of the analog channel, respiration measurement does not disturb ECG measurement. The differential carrier is converted to a single-ended signal after pre amplification. The very low frequency (<1 Hz) respiration signal modulated on the carrier signal can be considered as a slow varying DC signal. To extract this DC signal an active full wave rectifier is used followed by a Sallen Key low pass filter. The obtained respiration signal is too small (in the microvolt range) to be directly digitized. Therefore, an adjustable post amplifier is used to amplify this signal. The amplified respiration signal is finally converted from analog to digital and then, the digitized signal can be read out by the on-chip DSP.

Additionally, different amplifier designs have been investigated and developed for recording bio potentials such as cortical signals as indicated by Hogervorst and Huijsing (1996), Lee et al (2006), Fan et al (2008). These amplifiers are usually used in implantable biomedical devices with the amplifier inputs connected to microelectrode arrays. Bio-potentials obtained from the microelectrode arrays usually have a power spectrum between a few Hertz and a few kilo-Hertz with an amplitude range between a few micro-Volts and a few tens of milli- Volts. The most commonly used bio-medical signals amplitude and frequency range is provided in Table 4.1.
Table 4.1 Commonly used Biomedical Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Frequency</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG</td>
<td>0.05-250Hz</td>
<td>5µV-8mV</td>
</tr>
<tr>
<td>EEG</td>
<td>0.5-100Hz</td>
<td>2µV-200µV</td>
</tr>
<tr>
<td>EP</td>
<td>2KHz-5KHz</td>
<td>20nV-20µV</td>
</tr>
<tr>
<td>EMG</td>
<td>0.01Hz-10KHz</td>
<td>50µV-10mV</td>
</tr>
</tbody>
</table>

As a result, the amplifiers are required to have low input referred noise. Since there are many amplifiers in an implantable biomedical device, the overall power dissipation of the amplifiers has to be kept very low such that the entire device can be powered directly by inductive coupling from an RF field or from an inductively rechargeable battery. To effectively use the available power in the implantable device, the supply voltage has to be low as long as the output signal swing and the dynamic range are not degraded. A low power, low voltage rail-to-rail amplifier is developed for amplification, buffering, etc. This amplifier acts as a preamplifier in the analog front end of a system on Chip (SoC) architecture as shown in Figure 4.2.

Figure 4.2 System Architecture of Entire System on Chip
4.3 CONVENTIONAL OPAMP ARCHITECTURE (COPAMP)

The objective of this work is to implement the most promising, programmable, low power and low noise operational amplifier as a preamplifier for biomedical applications. It should consume less power, offer less noise and amplifies the weak cortical input signals to a larger extent. The conventional opamp architecture, given by Jakob et al (2008) has good gain, power and noise performance and is made to work within a programming range of being in low noise mode at one end and low power mode at the other. The complete schematic of the opamp is shown in Figure 4.3.
The rail to rail input stage is formed by the transistors M1-M4. The folded cascode stage consists of transistors M5-M20 with M21 and M22 transistors forming the class AB output stage. The programmability of the opamp is ensured by transistors M23, M25-M33 which forms the constant $g_m$ stage. The external bias currents $I_{\text{diff}1}$, 2 and $I_{\text{abn,p}}$ are set to make the opamp work in low power, medium power and high power mode. This in turn accomplishes the programmability of the opamp. The biasing voltage $V_{\text{bcn}}$ and $V_{\text{bcp}}$ acts as reference voltage for the cascode stage and $C_c$ is used for miller compensation.

When the common mode voltage, $V_{\text{cm,in}}$ is set at half the supply voltage, M23 is biased to carry half current of $I_{\text{diff}1}/2$ to the current mirror formed by transistors M24 and M25. So the NMOS and PMOS input stage carries equal current of $I_{\text{diff}1}/2$ resulting in constant transconductance value. $I_{29}$ and $I_{30}$ are set to carry current of $I_{\text{diff}1}/4$ by M26 transistor and same current is set to ID32, ID33. Current $I_{\text{diff}2}$ is distributed between M27 and M31. If $V_{\text{cm,in}}$ reaches large value, P-MOS input pair and M23 is turned off setting $I_{32}, I_{33}$ to $I_{\text{diff}2}/2$. So, the current $I_{\text{diff}1}$ is carried only by the N-MOS pair doubling the transconductance value. When $V_{\text{cm,in}}$ reaches lower value, N-MOS input pair shuts off and ID29, ID30 is set to $I_{\text{diff}1}/2$. So, the current $I_{\text{diff}2}$ is now carried only by the P-MOS pair doubling the transconductance value. Thus, the programmability of the opamp is achieved with input transistors biased in weak inversion region and output transistors biased in strong inversion region. So, the relation in Equation (4.1) is obtained.

$$\frac{g_{m22}}{g_{m4}} = \frac{\sqrt{ID_{22}}}{ID_4}$$  \hspace{1cm} (4.1)$$

$I_{\text{diff}1}$ and $I_{\text{diff}2}$ are used as bias currents for the input stage and external currents $I_{\text{abn}}$ and $I_{\text{abp}}$ are used for the folded cascode and output
stage. Proper setting of these currents makes the opamp to work in low power mode \((P_{\text{low}})\) medium power mode \((P_{\text{medium}})\) and high power mode \((P_{\text{high}})\).

4.3.1 Opamp Design using Low Supply Voltage

The minimum supply voltage to be maintained by the opamp is set by biasing the folded cascode transistors in strong inversion region. Equations (4.2) and (4.3) represents the constraints for the minimum supply voltage with the overdrive voltage \(V_{ov} = V_{gs} - V_{th}\).

\[
V_{dd} \geq 5 \times V_{ov} \tag{4.2}
\]

\[
V_{dd} \geq 2 \times V_{gs} + V_{ov} \tag{4.3}
\]

With maximum threshold voltage, Equation (4.3) can be modified as

\[
V_{th, \text{max}} \leq \frac{1}{2} \times (V_{dd} - 3 \times V_{ov}) \tag{4.4}
\]

The minimum supply voltage obtained with an overdrive voltage of 0.2 V is 1V. In this design, a 1.2 V supply voltage is maintained to satisfy Equation (4.2).

The conventional opamp obtains gain of 95dB, CMRR of 105dB and slew rate of 0.13V/µs. In biomedical measurements, the common mode rejection ratio (CMRR) is an important parameter indicating the ability to reject the power line interference. The Linearity, Power Supply Rejection Ratio (PSRR) and Signal to Noise ratio (SNR) are all related to CMRR. There are two important limitations to be considered for CMRR calculation, when active electrodes are used. One is the potential divider effect i.e. any difference in the skin electrode impedance will limit the maximal CMRR. Another important limitation is that while increasing the output resistance of the amplifier using the electrodes, the gain of amplifier is affected. The
CMRR and gain can be improved by replacing diode connected transistors in conventional opamp structure by current mirror circuits. Thus, four different architectures are designed and proposed with different type of current mirror circuit and their performances are analyzed.

4.4 PROPOSED OPAMP ARCHITECTURE

The current mirror is one of the basic building blocks of analog integrated circuits. A current mirror is a circuit designed to copy current through one active device by controlling the current in another active device of a circuit, keeping the output current constant regardless of loading. The current being 'copied' can be, and sometimes is, a varying signal current. Conceptually, an ideal current mirror is simply an ideal current amplifier. The current mirror is used to provide bias currents and active loads to circuits.

There are three main specifications that characterize a current mirror. The first is the current level it produces. The second is its AC output resistance, which determines to what extent the output current varies with the voltage applied to the mirror. The third specification is the minimum voltage drop across the mirror necessary to make it work properly. This minimum voltage is dictated by the need to keep the output transistor of the mirror in an active mode. The range of voltages where the mirror works is called the compliance range and the voltage marking the boundary between good and bad behavior is called the compliance voltage. Current mirrors are used in order to achieve a higher accuracy, higher output impedance and thus a higher gain as well. Hence, in the conventional architecture, the diode connected transistors M17, M18, M19, M20 are replaced with Simple, Widlar, Cascode and Wilson current mirror circuits and their performances are compared.
4.4.1 Proposed Opamp with Simple Current Mirror I –Popamp I

The proposed biomedical opamp with simple current mirror includes simple current mirror at its output stage. An ideal current mirror is a circuit with infinite output impedance, zero input resistance and minimum output voltage as indicated in John and Martin (1997). The simple current mirror circuit is shown in Figure 4.4.

Figure 4.4 Simple Current Mirror

The transistors M1 and M2 are in the saturation region. A reference current flows through the diode connected transistor M1 and the same amount of current is mirrored at the output. The minimum output voltage is Von and the output resistance rout = rds. The output impedance is low in submicron technologies and the current gain accuracy is poor since V_{DS1} ≠ V_{DS2}. In the conventional biomedical opamp the diode connected transistors M17, M18, M19 and M20 at the output side are replaced with N-MOS simple current mirrors M17 and M18 and P-MOS simple current mirrors formed by the transistors M19 and M20 as shown in Figure 4.5.
The bias currents for the input stage are set by the external currents $I_{\text{diff1}}$ and $I_{\text{diff2}}$. Here, the external bias current values for the input stage are taken as $286\mu\text{A}$ for low power and low noise mode. The bias currents for the folded cascode and output stage are set by the external currents $I_{\text{abn}}$ and $I_{\text{abp}}$. Here the external bias current values for the folded cascade stage and output stage are taken as $30\mu\text{A}$ to bias transistors in strong inversion region. Simulation and measurement is done with $|I_{\text{diff1}}| = |I_{\text{diff2}}|$ and $|I_{\text{abn}}| = |I_{\text{abp}}|$. Figure 4.6 gives the gain of the proposed opamp with simple current mirror and the value is found to be $97.03$ dB.
Figure 4.6 Gain plot of the Popamp I

The settling time behavior of the proposed opamp is shown in Figure 4.7 (a) and (b) and the slew rate is found to be 0.96V/μs

Figure 4.7 (a) Step input to the Popamp I
Figure 4.7(b)  Settling time output of the Popamp I

The AC analysis performed on the proposed opamp is shown in Figure 4.8 and the CMRR is found to be 97.35dB.

Figure 4.8 CMRR of the Popamp I
The proposed opamp with simple current mirror achieves more gain, CMRR and slew rate compared to conventional opamp. Also, the input thermal noise is calculated to be lesser than conventional structure though the THD and power remains more or less the same as the conventional opamp. The unity gain frequency is found to be 9.53MHz and is slightly lesser than the conventional opamp.

4.4.2 Proposed opamp with Widlar Current Mirror II- Popamp II

This proposed opamp has widlar current mirror at the output stage. The widlar current source circuit is shown in Figure 4.9. It uses source degenerated resistors $R_1$, $R_2$ in its configuration. So it has tradeoff between power and area as there is practical limitation on choosing the resistor value. Thus, it is better if transistors are replaced with resistors though the performance is improved in terms of input thermal noise.

![Figure 4.9 Widlar Current Mirror](image)
In the conventional biomedical opamp the diode connected transistors M17, M18, M19, and M20 at the output side are replaced with the widlar current mirrors formed by the transistors M17, M18, M19 and M20 and resistors R, as shown in Figure 4.10.

Figure 4.10 Schematic of Popamp II

Figure 4.11 gives the gain of the Popamp II and the value is found to be 77.85 dB.
Figure 4.11 Gain plot of the Popamp II

Settling time behavior is performed for the popamp II with the voltage follower configuration. Figure 4.12(a) and (b) shows the settling time input and output of the popamp II. The obtained slew rate is 1.8V/µs.

Figure 4.12 (a) Step input to the Popamp II
The frequency analysis is performed for the proposed biomedical opamp with common mode configuration and Figure 4.13 shows the CMRR output of the proposed bio-medical opamp to be 93.42 dB.

Figure 4.12 (b) Settling time output of the Popamp II

Figure 4.13 CMRR of the Popamp II
Though there is increase in slew rate and unity gain frequency compared to conventional opamp, the proposed opamp with widlar current mirror has a lesser gain and CMRR due to the restriction placed on the resistor. The input thermal noise is found to be lesser than both the conventional opamp and proposed opamp I but the THD and power remains more or less the same as the conventional opamp.

4.4.3 Proposed Opamp with Cascode Current Mirror III - Popamp III

In this proposed biomedical opamp, cascode current mirror is used at its output stage. In a cascode current mirror, cascoding increases the accuracy and transistors are connected as shown in Figure 4.14. The output resistance is given as \( r_{out} = g_m r_{ds}^2 \) and current gain is excellent as \( V_{DS1} = V_{DS2} \). Thus, the output resistance and current gain accuracy is improved.

![Figure 4.14 Cascode Current Mirror](image)
In the conventional opamp architecture, diode connected transistors M17 and M18 are replaced with NMOS cascode mirror transistors M17, M18, M36 and M37 and diode connected transistors M19 and M20 are replaced with PMOS cascode mirror transistors M19, M20, M34 and M35. So, it includes both NMOS and PMOS current mirror at the output stage to increase the gain and CMRR and reduce the noise level, as shown in Figure 4.15.

![Figure 4.15 Schematic of Popamp III](image)

Figure 4.15 Schematic of Popamp III

Figure 4.16 gives the gain of the proposed bio-medical opamp with cascode current mirror and the value is found to be 97.75 dB.
The settling time behavior of the proposed opamp III is shown in Figure 4.17 (a) and (b). The slew rate is obtained as 3.51V/μs.

Figure 4.17 (a) Step input to the Popamp III
A CMRR of 112.41dB is obtained when AC analysis is performed to the opamp III and is shown in Figure 4.18.

Cascode stages are widely used in different circuits to boost up gain in amplifiers or to obtain a higher precision on current mirrors, without adding new current-consuming stages. In the opamp circuit, the cascode current mirror outperforms in terms of CMRR, Gain, Slew rate and noise.
compared to conventional opamp and proposed opamp I and II. The THD, unity gain frequency and power is comparable with the conventional structures and proposed opamp I and II, though there is an increase in number of transistor count, which slightly increases the power dissipated.

4.4.4 Proposed Opamp with Wilson Current Mirror IV- Popamp IV

The proposed biomedical opamp is designed with wilson current mirror at the output stage. The modification of cascode current mirror is a Wilson current mirror which performs approximately the same as a cascode current mirror. The circuit diagram of the wilson current mirror is shown in Figure 4.19. It uses a shunt series feedback to increase the gain accuracy. The output resistance is quite the same as that with cascode current mirror. However, setting up the output voltage constant is difficult. When the output current increases, the output voltage also increases by two times the square root of output current. Due to this reason, a cascode current mirror circuit present in John and Martin (1997) outperforms all the other current mirrors.

![Wilson Current Mirror](image)

Figure 4.19 Wilson Current Mirror
In the conventional biomedical opamp, diode connected transistors M17 and M18 are replaced with NMOS Wilson mirror transistors M17, M18, M36 and M37 and diode connected transistors M19 and M20 are replaced with PMOS Wilson mirror transistors M19, M20, M34 and M35 as shown in Figure 4.20.

Figure 4.20 Schematic of Popamp IV

Figure 4.21 gives the gain of the proposed biomedical opamp with Wilson current mirror and the gain is found to be 71.52 dB.
Figure 4.21 Gain plot of the Popamp IV

The settling time behavior of the proposed opamp with wilson current mirror is shown in Figure 4.22 (a) and (b). The slew rate is obtained as 0.16V/µs.

Figure 4.22 (a) Step input to the Popamp IV
A CMRR of 91.06dB is obtained when AC analysis is performed to the opamp with Wilson current mirror and is shown in Figure 4.23.

The proposed opamp has a lesser gain and CMRR due to the shunt series feedback connection of the wilson current mirror. There is an increase
in power though slew rate and input thermal noise performance improves when compared to conventional opamp. The THD remains the same and unity gain frequency is found to be 9.65 MHz.

The opamp’s architecture is implemented using H-Spice in Synopsis tool under 1.2V supply with CMOS 0.13 µm technology. Performance parameters of the conventional opamp with diode connected transistors are compared with the proposed opamp with current mirror circuits and the results are tabulated in Table 4.2.

### Table 4.2 Comparison of Existing and Proposed Architectures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Copamp</th>
<th>Popamp I</th>
<th>Popamp II</th>
<th>Popamp III</th>
<th>Popamp IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>V</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Open Loop Gain</td>
<td>dB</td>
<td>95</td>
<td>97.03</td>
<td>77.85</td>
<td>97.75</td>
<td>71.52</td>
</tr>
<tr>
<td>CMRR</td>
<td>dB</td>
<td>105</td>
<td>97.35</td>
<td>93.42</td>
<td>112.41</td>
<td>91.06</td>
</tr>
<tr>
<td>Unity Gain Frequency</td>
<td>MHz</td>
<td>9.74</td>
<td>9.53</td>
<td>9.65</td>
<td>9.2</td>
<td>9.82</td>
</tr>
<tr>
<td>Total Harmonic Distortion @ 1Vpp, 1Khz</td>
<td>dB</td>
<td>-75.352</td>
<td>-75.352</td>
<td>-75.35</td>
<td>-75.354</td>
<td>-75.118</td>
</tr>
<tr>
<td>Input Thermal Noise (@ 200k)</td>
<td>nV/√Hz</td>
<td>4.84</td>
<td>2.92247</td>
<td>2.7416</td>
<td>2.155</td>
<td>2.1016</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>V/µS</td>
<td>0.13</td>
<td>0.96045</td>
<td>1.805</td>
<td>3.5115</td>
<td>0.16309</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>mW</td>
<td>0.719</td>
<td>0.722</td>
<td>0.759</td>
<td>0.73</td>
<td>0.719</td>
</tr>
<tr>
<td>Load conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_L$</td>
<td>Ω</td>
<td>22k</td>
<td>22k</td>
<td>22k</td>
<td>22k</td>
<td>22k</td>
</tr>
<tr>
<td>$C_L$</td>
<td>F</td>
<td>13.5p</td>
<td>13.5p</td>
<td>13.5p</td>
<td>13.5p</td>
<td>13.5p</td>
</tr>
</tbody>
</table>
It is inferred from the table that, the proposed bio-medical opamp with cascode current mirror circuit excels in its performance compared to proposed opamp with other current mirror circuits and conventional opamp structure. It achieves the highest gain of 97.7554 dB, low noise of about 2.155 nV/√Hz at 200 kHz, CMRR of about 112.41 dB, THD of about -75.354 dB and slew rate of about 3.5115 V/µS under 22 kΩ and 13.5 pF load.

The programmability of the proposed opamp with cascode current mirror is described here. Figure 4.24 gives the programmability of the proposed opamp with input common mode voltage Vs unity gain frequency.

![Figure 4.24 Input Common Mode Voltage Vs. Unity-Gain Frequency](image)

Figure 4.24 gives the programmability of the proposed opamp with input common mode voltage Vs transconductance.
Figure 4.25 Input Common Mode Voltage Vs. Transconductance

The graph shows that input common mode voltage is varied from Gnd +100mV to Vdd- 100mV to verify constant gm stage and unity frequency. The proposed opamp obtains maximum frequency and transconductance when the input common mode voltage is maintained at half the supply voltage. Thus the programmability of the proposed opamp with cascode current mirror is verified.

4.5 CONCLUSION

A 130nm programmable CMOS operational amplifier with different types of current mirror has been proposed. Among them the opamp proposed with cascode current mirror consumes very less power, offers less noise and it amplifies the weak cortical input signals to a larger extent. Simulation results prove that the proposed opamp shows an improvement in gain of about 2.755 dB, common mode rejection ratio of about 7.41 dB, slew rate of about 3.3815 V/µS and reduction in noise of about 2.685 nV/√Hz compared to that of the conventional opamp. So, the proposed opamp can be used as a preamplifier in biomedical applications. In the similar way, ECG signal acquisition using OTA as preamplifier and Second Order Gm-C filter as low pass filter is discussed in next chapter.