ULTRA LOW POWER AMPLIFIER FOR BIOPOTENTIAL SIGNAL ACQUISITION SYSTEM

A Dissertation-II Proposal

Submitted By

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To

Department Of Electronics And Communication Engineering

In partial fulfillment of the requirement for the

award of degree of

Master Of Technology in Electronics And Communication Engineering

Under the guidance of

Dr. Anita Kumari

Department of Research and Development

DECLARATION

I hereby declare that the dissertation II proposal entitled, **ULTRA LOW POWER AMPLIFIER FOR BIOPOTENTIAL SIGNAL ACQUISITION SYSTEM** submitted for the M.Tech Degree is entirely my original work and all the ideas and references have been duly acknowledged. It does not contain any word for the award of any other degree or diploma.

Date:

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CERTIFICATE

This is to certify that K.PRATYUSHA has completed M.Tech dissertation-II proposal titled **ULTRA LOW POWER AMPLIFIER FOR BIOPOTENTIAL SIGNAL ACQUISITION SYSTEM** under my guidance and supervision. To the best of my knowledge, the present work is the result of her original investigation and study. No part of the dissertation proposal has ever been submitted for any other degree or diploma. The dissertation proposal is fit for the submission and the partial fulfillment of the conditions for the award of M.Tech Electronics and Communication Engineering.

Date: …….

Signature of Advisor

NAME: Dr. Anita Kumari

ABSTRACT

In biomedical field there is a great need of VLSI in designing integrated bioamplifier circuits which performs the operation of amplifying low amplitude and low frequency signals. Due to excessive demand of implantable and wearable devices for processing biopotential signals, a low power bioamplifier is proposed in this paper and power dependency of bioamplifier on different current mirror configuration is discussed. In proposed bioamplifier architecture, cascode configured OTA is used to increase the gain and lower the power consumption of the circuit. All transistors in OTA are operating in weak inversion region consuming nanoamperes of current. Proposed bioamplifier is designed using 180 nm CMOS process technology with a supply voltage of 1.8 V. Simulated results shows, bioamplifier is operating with a low power dissipation of 6.25 uW, midband gain of 45.38 dB and passes signals in the frequency range of 5.02 Hz to 2.927 KHz.

ACKNOWLEDGEMENT

This is a humble effort to express my sincere gratitude towards my mentor who has guided and helped me to explore the field of Biomedical Instruments which is the base of my Dissertation undertaking. Problem formulation is a major milestone for a student while working on Dissertation. As such this subject was a challenge for me and was an opportunity to prove my caliber. Being a beginner, I faced many problems, which would have frustrated me. I am highly grateful and obliged to my mentor. It would not have been possible to see through the undertaken field of study without the guidance of **Mrs. Anita Kumari** It was purely on the basis of her experience and knowledge that I am able to clear the theoretical and technical hurdles during the analyses and exploration of the selected field of study.

I would like to thank the **Project Approval Committee members** for their valuable comments and discussions and I would also like to thank **Lovely Professional University** for facilitating me to undertake this study.

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CHAPTER 1

INTRODUCTION

1.1 BIOPOTENTIAL SIGNALS

Biopotential signals are generated due to the electrochemical activities inside the cell and these are of different types depending upon the types of cells or tissues from which they are generated. Electroencephalogram (EEG) signals are generated due to the neural activities inside the brain, Electrocardiogram (EKG) signals are due to the pumping activities of the heart, Electromyogram (EMG) signals are due to the skeletal muscles activities.

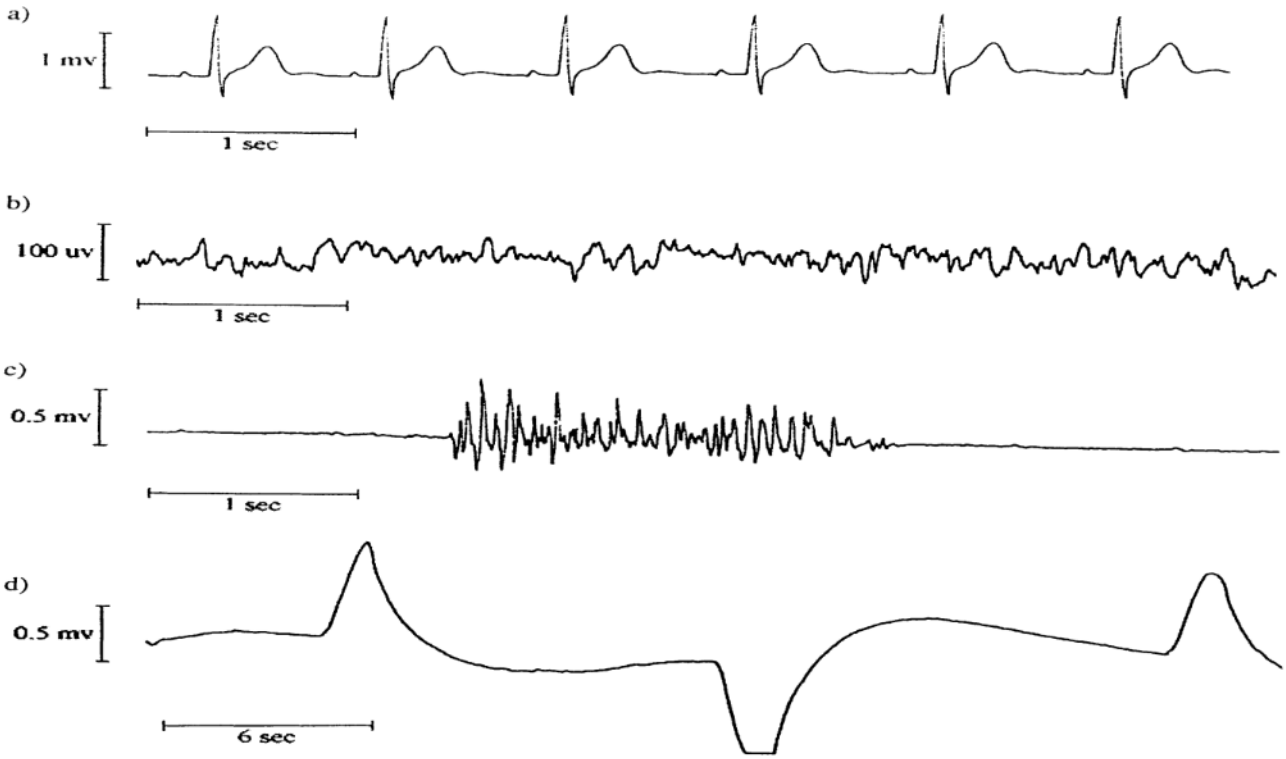

Figure.1.1.1 a)ECG b) EEG c) EMG d)EOG

Initially cells are in rest position exhibiting the resting potential, due to the exchange of ions through the cell membrane electrical activity occurs. When cell is at rest position it is more permeable to K^+ ions instead of Na^+ ions and at this time concentration of K^+ ions inside the cell membrane is more than that of the outside of the membrane. So due to the difference in the concentration gradient the K^+ ions are diffused from interior to the exterior making interior of the membrane more negative and due to this diffusion gradient electric field is generated. Generated electric field is used to maintain equilibrium of ions maintaining a potential of -70mv. When cells are electrically stimulated through the central nervous system membrane is more permeable to Na^+ ions than K^+ ions. So Na^+ ions starts diffusing towards the inner side of the cell and this process continues till the potential reached to +40 mv. After this operation Na^+ ions permeability decreases and K^+ ions permeability increases, which results in sharp decrease in membrane potential towards its rest state. This cycle of the cellular potential is called the action potential. All the biopotential signals like ECG, EMG, EEG are generated due to this action potential occurs in our body cells.

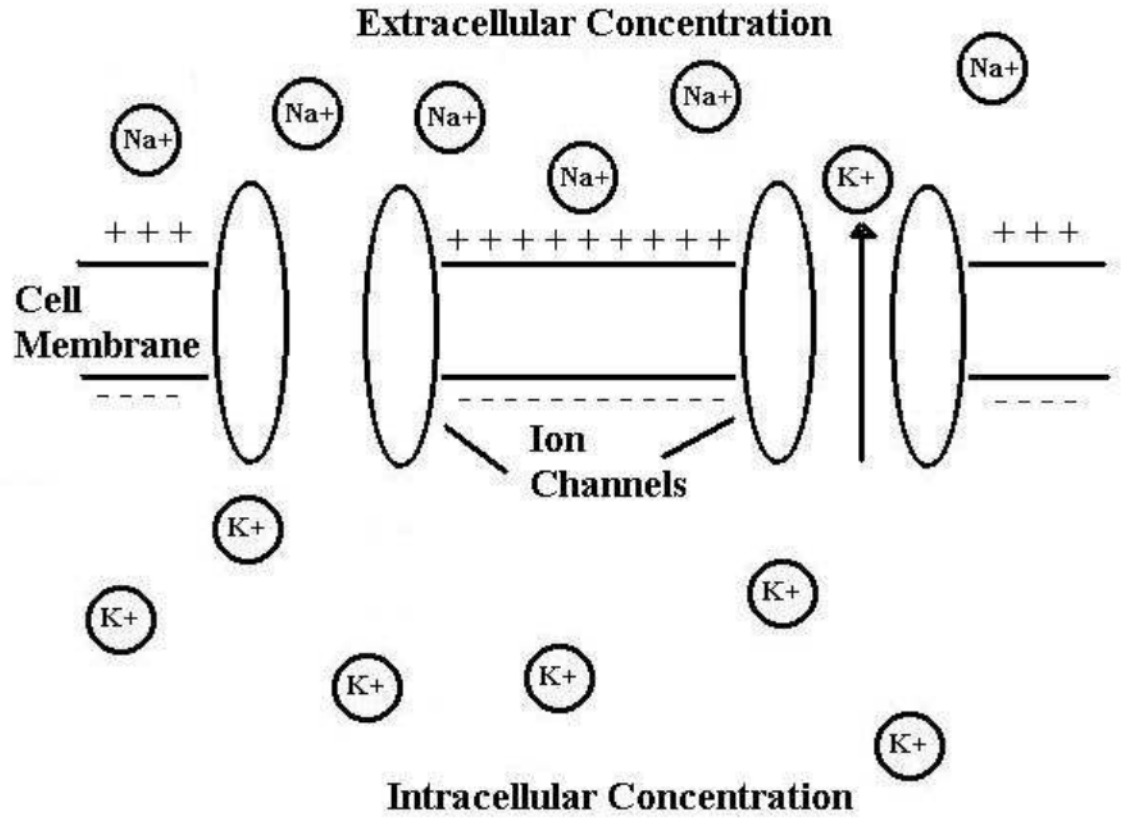

Figure.1.1.2 Origin of Biopotential signals

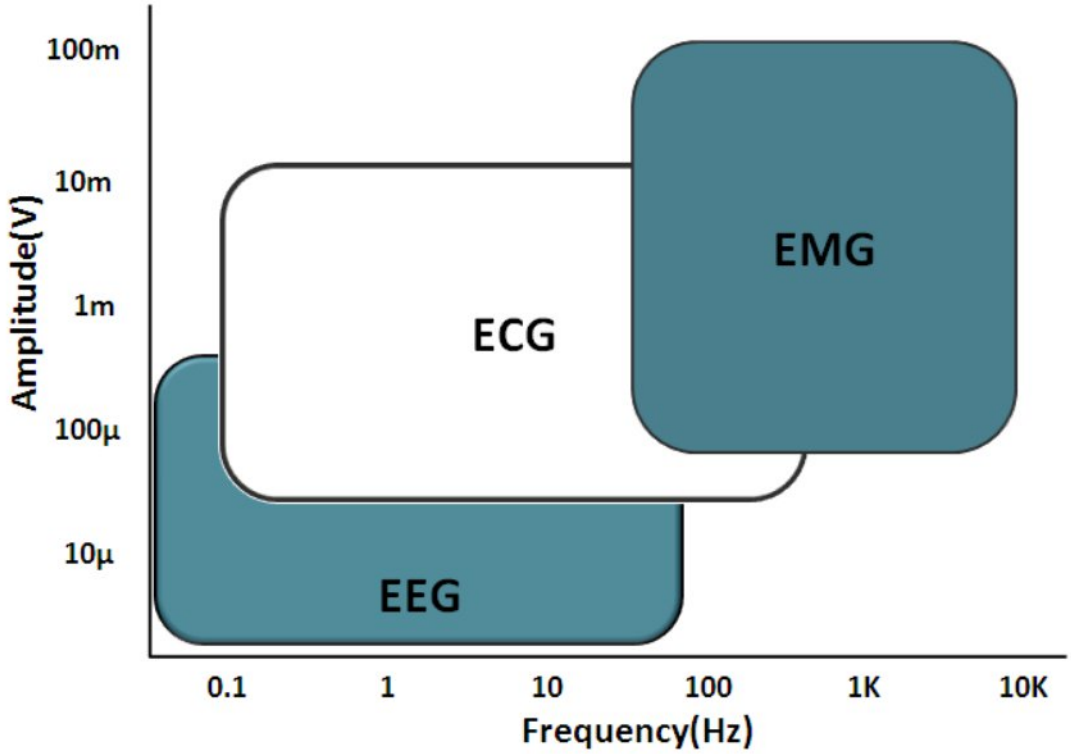

Figure.1.1.3 Biopotential signals amplitude and frequency characteristics

1.2 BIOPOTNTIAL ELECTRODES

Biopotential signals can be captured invasively or non-invasively using electrodes, in case of invasive electrodes are placed inside brain through neurological surgery and in non-invasive electrodes are arranged in a cap like format. A connection is created between brain cells and bioamplifier with the help of electrodes. Current generated in our body is due to the movements of ions but in bioamplifier current is developed due to the electron motion. Hence electrode is acting like an interface between metal and electrolyte. When chemical reaction occurs between metal and electrolyte free electrons are generated. Due to this, the neutrality that was maintained between the metal and electrolyte disturbed and electron gradient is created due to which current flow occurs.

There are different types of electrodes and one of these electrodes are used for acquiring biopotential signals according to the required application. Electrodes are classified into dry, wet and non-contact electrodes.

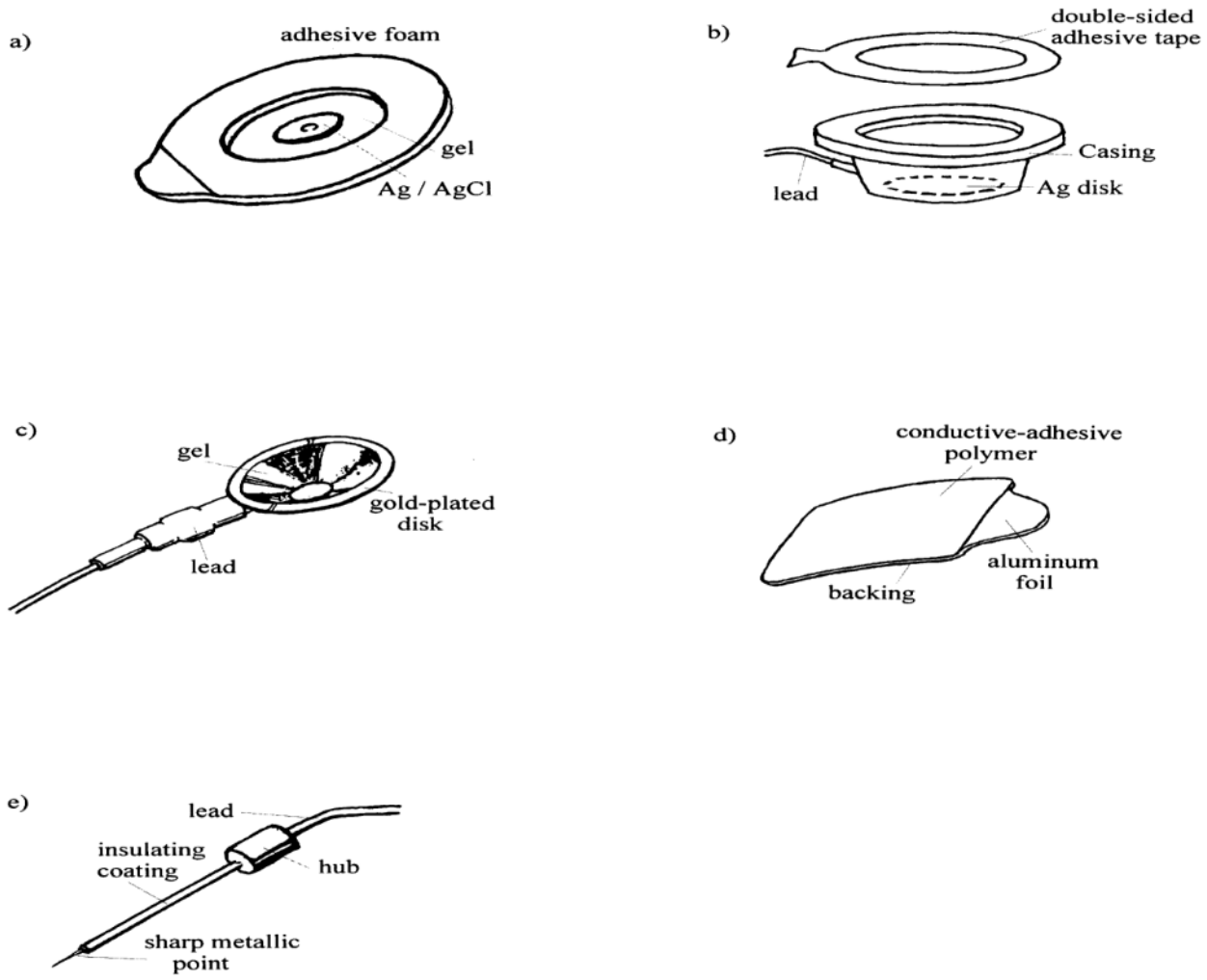

Figure.1.2.1 a)Ag/AgCl electrode b)Gold electrode c)Conductive polymer electrode d)Metal or carbon electrode e)Needle electrode

Dry electrodes are placed directly on the body surface and these type of electrodes are more comfortable for patients. But these are having a disadvantage of having a very high contact resistance between body surface and electrodes. Wet electrodes are placed on body surface by using a gel like substance and through this we can acquire data more efficiently, though these electrodes are disposable at every time for acquiring signals new electrodes are used. Wet electrodes are made up of Ag or Agcl material and in hospitals generally these electrodes are used. In non contact electrodes physical contact is absent between the body surface and electrode These electrodes behaves capacitively and some of them are :

- **Ag/AgCl Electrodes:** This type of electrode design consist of a highly conductive metal silver and electrodes design provides lowest and stable junction potentials. Due to the electrolytic interface junction potential is generated, so a gel made up of sodium or potassium chloride is used in electrodes.

- **Gold Electrodes:** Gold plated electrodes are having higher conductivity and these types of electrodes are mainly used as EEG electrodes. These are used in case of EMG also. But these are more expensive than Ag/Agcl electrodes at the same time it is having lower impedance.
- **Conductive polymer Electrodes:** These are generally conductive and adhesive. The polymers which are having the adhesive properties are selected and if some monovalent metal are attached to them then it become conductive. These types of electrodes don't require additional adhesive materials.
- **Metal or Carbon Electrodes:** Metal electrodes are bulky but provides the advantage of reusable and inexpensive. These are having high resistivity and nosier.
- **Needle Electrodes:** Nature of these electrodes are invasive and are mainly used when there is a necessary that the signals to be recorded from the organ directly. As these electrodes are invasive these are used in research applications.

1.3 SKIN PREPARATION FOR SURFACE ELECTRODES

Before placing the electrodes on the surface of skin, skin is need to be prepared. Skin preparation means sometimes there are dead layers of skin on the surface and this dead layer of skin provides large resistance by which the bio-potential signals that are captured from the skin have lower amplitude levels. So for that we need to remove the dead layer of skin by slightly rubbing that place using some abrasive material. Generally alcohol is used to clean the skin before electrode application[22].

1.4 BIOPOTENTIAL AMPLIFIER

As biopotentials signals are very weak in nature and amplitude is in the range of microvolts or millivolts, it becomes very difficult for the physicians to analyze the signals. So if acquired signals are converted in the range of volts than it will be very helpful for the physicians for analysis. The conversion of these signals from microvolts to volts range can be possible with the help of the amplifiers. The amplifier that is used for the amplification of the bio-potential signals is called bio-potential amplifier. In case of medical instruments generally we use instrumentation amplifier as the biopotential amplifier[20].

Tremendous research is going on, in the field of biomedical for enhancing the quality of biopotential acquisition systems which became a challenging task for the scientists. Bioamplifier circuit is a crucial part of this system which is being used for amplification of biopotential signals that are generated due to electrochemical activities inside the cells. Biopotential signals are of different types depending upon the types

of cells or tissues from which they are generated. Electroencephalogram(EEG),Electrocardiogram(EKG), Electromyogram(EMG) signals are generated due to the neural activities inside the brain, pumping activities of the heart and skeletal muscles activities respectively. All biopotential signals like ECG, EMG, EEG are generated due to action potential occurs in body cells. Biopotential signals are having amplitudes in the range of micro volts or mill volts with low frequency range. During acquisition of biopotential signals with the help of electrodes, dc offset voltages generated due to difference in the half cell potentials are coupled with input signal. DC offsets amplitude, which is in the mill volts range dominates required input signals that are in micro volts and due to this reason offset voltage should be rejected before amplifying input signal otherwise processed input signal is distorted at output[32].

Bioamplifier should have the ability to amplify only desired signals while rejecting all the unwanted signals. In other words, bioamplifier should have frequency characteristics suitable for kind of biopotentials that is being acquired. Figure.1.1.3 shows the frequency and amplitude characteristics of biopotential signals. As biopotentials are very weak in nature, input referred noise of amplifier should be very small such that bio-potentials can be easily detectable by acquisition system. Bioamplifiers, proposed in previous studies [1–3, 5] have used the MOS-bipolar pseudo resistors for large time constant, as a result amplifier will have low cutoff frequency. On chip capacitors are used for rejecting DC offset voltages, that are generated due to the electrode tissue interface. In this paper low power bioamplifier architecture is proposed, which can be used in implantable and wearable devices. In implantable and wearable devices low power circuits are highly recommended because high power dissipation[34] of circuit may hamper surrounding tissues of patients body.

Main contributions of this work are:

- Architecture proposed in this paper focus on implantable and wearable device applications in which power consumption of the bioamplifier is a very crucial parameter.
- In proposed OTA additional four transistors are used in cascoded configuration and two transistors in the second stage are eliminated to the architecture proposed in [1]. Resulted configuration provides, minimization of power consumption and enhancement of midband gain of the bioamplifier.
- Power consumption dependency of bioamplifier on Simple Current Mirror(SCM), Cascode Current Mirror(CCM), Wilson Current Mirror(WCM) configurations are discussed and a comparison is shown how the Wilson Current Mirror configuration provides better efficiency.

1.4.1THE EEG AMPLIFIER

EEG signals are in the range of microvolts so for proper analysis of the signal, it should be converted to the range of volts. So the amplifier which is used for amplification of these signals should have of very high gain. We know that there are different types of amplifier among them operational amplifier is having high gain parameter. But mostly in measurement purpose we are using INA though it's gain is limited because while capturing the signals through the electrodes a common mode signal is coupled with desired input signal. So we need to remove that common mode signal during the amplification stage. So in general op-amp the input signal along with the common mode signal is amplified at the output but in case of INA the common mode signal is rejected during the 1st stage of amplification with help of buffer circuit and at the output we get our desired amplified input signal[33]. But problem with INA(instrumentation amplifier) is that it is too bulky and consumes large power and area, so these are not suitable for implantable and wearable applications.

1.4.2 INSTRUMENTATION AMPLIFIER

The reason for selecting the INA as the biopotential amplifier is it posses the properties that are very essential for measuring any bio-potential signals like high differential gain, low common mode gain, high CMRR(ratio of differential gain to the common mode gain), high input impedance, low output impedance etc. Generally the instrumentation amplifier is made up of operational amplifiers[31].

Generally the INA is made up of 3 op-amps. It is divided into 2 gain stages and in the first stage 2 buffer amplifiers are used which provides input impedance matching, which makes it to be used in measurement purpose. 2nd stage is generally used as a differential amplifier. So when inputs are given to INA first these are passed through the buffer amplifiers where the interference signals that are coupled with the input signals are rejected and impedance is matched. Next these amplified difference signals are given to the 2nd stage amplifier for further amplification[10].

The overall gain of the INA is the multiplication of the gains of the both stages. $\left(\frac{R_3}{R_2}\right)$ is the gain of the differential amplifier and $\left(1+\frac{2R_1}{R_{gain}}\right)$ is the gain of the first stage. When R_{gain} resistor is removed than amplifiers in the input stage simply behaves like an unity buffers and in that case the gain will becomes $\left(\frac{R_3}{R_2}\right)$

.The gain of the buffer can be increased by adding a resistor between the inverting input and the ground. So instead of adding 2 resistors for 2 buffers we can use only one resistor R_{gain} between the 2 inverting inputs. This type of connection results in increase in differential gain and decrease in common mode gain, by which CMRR is increased. This type of connection helps in eliminating the problem of matching because only one resistor is used instead of two. So the overall gain also be increased by changing only one value.

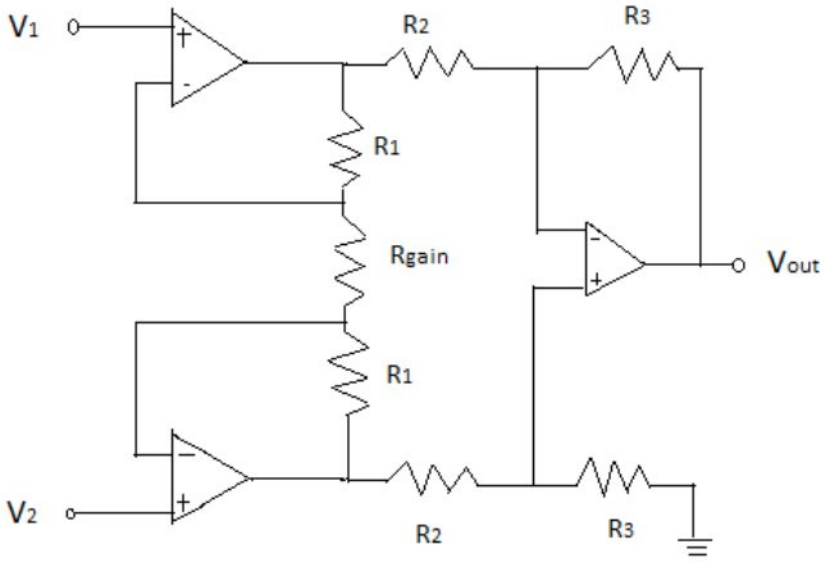

Figure.1.4.2.1 3 op-amp instrumentation amplifier

$$\frac{V_{out}}{(V_2 - V_1)} \left(1 + \frac{2R_1}{R_{gain}}\right)\left(\frac{R_3}{R_2}\right) \qquad (1)$$

$$CMRR \quad 20\log_{10}\left(\frac{A_D}{A_{CM}}\right) \qquad (2)$$

In ideal INA common mode gain is "zero" and common mode gain is caused due to the mismatch of the resistor pairs. To obtain the closely matched resistor pairs is a very difficult task. INA can be made up of 2 op-

amps instead of 3 by considering the power consumption parameters. Generally in the INA IC the resistors are matched by using laser trimming technique so in that case CMRR is very high.

1.4.3 PARAMETERS EFFECTING THE AMPLIFIER

While acquiring biopotential signals with the help of electrodes, dc offset voltage is coupled with the input signal and dc offset is due to the difference in the half cell potentials. So this offset voltage should be rejected before amplifying the input signal. Biopotential amplifier should be designed in such a way that it should have the ability to amplify only the desired bio-potential signal while rejecting all unwanted signals. In other words, the bio-potential amplifier should have frequency characteristics suitable for kind of biopotential that is being acquired[30].

As the biopotentials are very weak in nature, the input referred noise of the amplifier should be very small such that these bio-potentials can be easily detectable by the acquisition system. While designing an INA one should always aware of to reduce the interferences that are caused due to the unwanted sources.

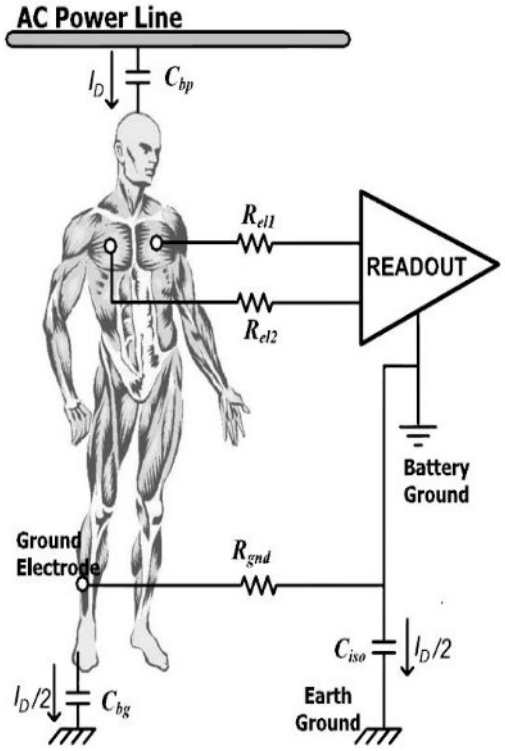

Figure 1.4.3.1 Electrostatic Interference to Human Body

The main unwanted sources of interference are electromagnetic and electrostatic interference. When an AC current flows through the conductor an EM field is created around the conductor[4]. This electromagnetic field cuts the loop around the conductor such that electromotive force is generated and it is similar to the generator operation principle. So when supply is given to bioamplifier from the main supply electromagnetic field is generated and this field cuts the loop created among the human body, electrodes and the bio-potential amplifier[25]. Due to this, an AC signal from the main supply created and is coupled with the input of the biopotentials. This signal is the common mode signal which is common to both of the inputs of the amplifier

Interferences can also be due to the electrostatic effects. This effect can be explained by considering the above figure. From the Figure.1.4.3.1 it shows that capacitance generated between the mains supply and our body is given as C_{bp} and capacitance between the body and ground is given as C_{bg}. There is one more capacitance that is connected between the earth and circuit ground denoted as C_{iso}. Resistances between body surface and the front end of the biopotential amplifier is given as R_{e1} and R_e . So current I_D flows into the body through the C_{bp} and current is distributed among the C_{ISO} and C_{bg}. Due to this reason, voltage is generated and the R_{gnd} appears as the common mode signal at the inputs of the biopotential amplifier.

As the main cause of interferences in the amplifiers are due to the electromagnetic and electrostatic interference, biopotential amplifier should be designed with a very good CMRR. In case of bio-potential amplifier CMRR is a very crucial parameter. Power consumption is another parameter that we need to consider while designing the bioamplifier.

1.4.4 BIO-POTENTIAL AMPLIFIER SPECIFICATIONS

- **Gain:** Biopotential signals that are captured from our body cells are generally low in amplitude in the range of milli volts or micro volts[28]. During the diagnosis of the patient signals should be amplified so that it will be easy for analyzing the signals. So for this the biopotential amplifier should have gain in the range of 1000. Generally we measure the gain in decibels(dB) and linear gain is transformed into decibels by using the following formula

$$\text{Gain(dB)} = 20\log(\text{linear gain}) \qquad (3)$$

- **Frequency Response:** The biopotential amplifier bandwidth should be such that it amplifies all the signal frequencies present in that particular range. The bandwidth can be defined as the difference between the upper cutoff frequency and the lower cutoff frequency. The gain of the cutoff frequencies

decreased by 70.7% of the mid frequency range. These cutoff frequencies are also called as half power points because at this frequency the signal power is$(0.707)^2$=0.5 and these are also known as -3dB points.

- **Common Mode Rejection:** As the human body is a good conductor of electricity, when we are connecting power supply to our body then a 50/60 Hz interference signal is coupled with the original signal. This interference signal is having very high amplitude as compared to the original bio-potential signal and it interrupts the original signal. So we have to separate these two signals[. There is a term called CMRR(common mode rejection ratio) which rejects the common mode signal.

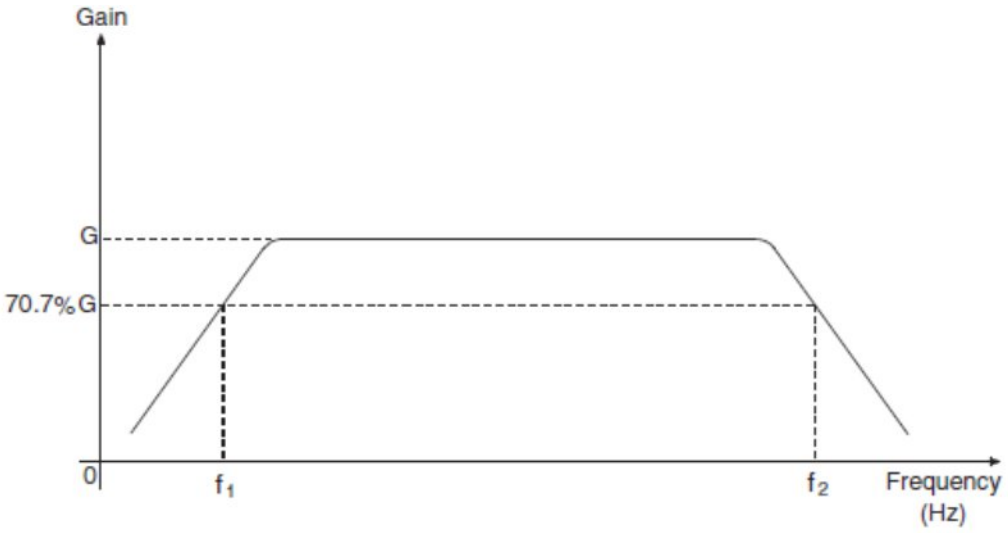

Figure 1.4.4.1 Frequency response of Bio-potential amplifier

- **Noise:** Noise is mainly generated due to the imperfections in the internal amplifier circuitry[35]. Generally it is measured in microvolt peak to peak or micro volts mean square (RMS)u_{rms}. It is applicable only when there is differential input voltage.

- **Recovery:** When we are capturing the biopotential signals from the body with the help of electrodes a certain offset voltage is generated and added with the input original signal and given to the input biopotential amplifier. That signals hampers the normal operation of amplifier and make the amplifier to go to the saturation state, after sometimes it goes back to its normal operation. The time taken by the amplifier to back to its normal operation is called recovery time.

- **Input Impedance:** Input impedance of the biopotential amplifier should be as high as possible so that it should not attenuate the required signals under measurement.

CHAPTER 2

LITERATURE SURVEY

This chapter discuss about the work already been done in the field of biopotential amplifier describing the various methods already been followed for the same which need to be understood for the further development in this field .

Shashank Dwivedi and A.K.Gogoi(2015) proposed an operational transconductance amplifier(OTA) with a supply voltage of 0.8V which can be used in the applications of realizing biopotential amplifier. Multi-tanh differential configuration and source degeneration are used to increase the linear range of the amplifier and DC shifting scheme is used to increase the common mode range[16]. All the transistors are working in the subthreshold region to get the low power. By using these techniques OTA is operating with open loop gain of 34.5dB, power consumption of 77.1uW, input referred noise of 24.18uV/sqrt(Hz).

Tzu-YunWang, Min-Rui-Lai, Christopher M. Twigg(2014) proposed a fully reconfigurable biopotential sensing amplifier in which floating gate transistors are used in this configuration to get the low cut off corner frequency. Amplifier is designed in the 0.35um CMOS process having specifications of midband gain of 40.7dB, input referred noise of 2.8uV/sqrt(Hz) and supply voltage of 2.5V[15].

Shang-Lin Wu, Po-Tsang Huang, Teng Chien Huang(2014) proposed the analog front end design[14] in which the differential difference amplifiers and DC offset rejection components are used. It is designed in 0.18um CMOS process with gain of 60.3dB and power consumption of 20.67uW for each channel, bandwidth of 2.32Hz to 6.61KHz, input referred noise of 0.826uV/sqrt(Hz).

Reza Abdullah and Dr. Edgar Sanchez-Sinencio(2013) proposed a technique to increase the common mode rejection ratio(CMRR) known as Dynamic Element Matching(DEM) scheme[13]. In this case

an amplifier with resistor capacitor feedback connection is designed and one opamp is used instead of three to built the INA for reducing the power consumption. As the CMRR is mostly effected due to the mismatch of passive components i.e resistors and capacitors DEM scheme is implemented to the RC feedback circuit.

Cheng C Liu(2013) introduced the biopotential amplifier with noise filtering application. In this paper transistors of the proposed bioamplifiers are working in the sub-threshold region such that power consumption will be less[5]. Because in the subthreshold region transistors operates by consuming very less current so automatically power consumption will be less. Bioamplifier is designed using 0.35um process.

K.A. Ng, Yong Ping Xu(2013) proposed the design of neural recording amplifier which eliminates the tradeoff between the input large capacitance and large area of the chip. The feedback single capacitor in the neural amplifier is replaced by a clamped T-capacitor network[12]. With this modification the amplifier achieves same gain with less area. This amplifier is designed in 0.35um CMOS process with a gain of 38.1dB, input referred noise 13.3uV/sqrt(Hz), bandwidth of 8.5KHz, input capacitance of 1pF and feedback capacitance of 20fF.

Fan Zhang, Jermy holleman, Brain.otis(2012) introduced the bioamplifier that is to be used in the front end acquisition system where we need a no of bioamplifiers. So they concentrated on lowering the power of the individual bioamplifier so that the overall power of the circuit decreasees. In this paper they introduced the closed loop complementary input amplifier. They designed the amplifier using 0.13um CMOS process with a bandwidth of 0.05Hz to 10.5 KHz ,input referred noise of 2.2uVrms and power dissipation of 12uW.

Yuhwai Tseng, Yingchieh Ho, Shouting Kao(2012) proposed the designing of the bioamplifier in which all the transistors are working in the subthreshold region with a supply voltage of 0.4V. They used the chopping technique and Gm-C filter for removing the flicker noise and suppressing the interferences respectively. They used the 0.18um CMOS technology for designing the amplifier with a power consumption of 0.09uW.

Wei Ming Chen, Liang TingKuo, Chung Wu Yu(2012) introduces a current mode technique for designing of the biopotential amplifier. Programmable gain stage and current mode filter is used for adjusting the gain and low cut off corner frequency. They designed the amplifier in 0.18um CMOS technology with power consumption of 13uW, input referred noise of 4.4uVrms and supply voltage of 1V.

Hossein Kassiri, Karim Abdelhalim and Roman Genov(2012) introduced the pseudo mos resistor design which gives value in the Giga Ohm range and is operated in the subthreshold region. These resistors are used in the feedback of neural amplifier and by varying the (W/L) ratios of the mos transistor the low cut off frequency of the band pass filter is adjusted. The amplifier is designed in the 0.13um CMOS process with a power consumption of 96nW , supply voltage of 1.2V and get the resistance of 500Gohm.

Vikram Chaturvedi and Bharadwaj Amrutur(2011) proposed the designing of neural amplifier in 130nm CMOS technology and all the transistors in the amplifier biased from 200nA to 2uA. They designed the amplifier with the mid band gain 37dB, input referred noise of 9.92uV/sqrt(Hz) to 3.9uV/sqrt(Hz), can passes the signal from 5Hz to 7KHz[7].

Vahid Majidzaden, Alexandre Schmid, Yusuf Leblebici(2011) introduced the bioamplifier[6] with low power consumption. The bioamplifier is designed in the 0.18um CMOS technology with a supply voltage of 1.8V having midband gain of 94dB , bandwidth from 10Hz to 7.2KHz , input referred noise of 3.5uV/sqrt(Hz), power consumption of 7.92uW.

S. Devarakond, B.Narayan, H.Sane, J. Zaveri(2009) introduced a new method which eliminates the low frequency noise. The amplifier is designed in the 0.5um CMOS process technology. They designed the amplifier with chopper stabilization technique[19]. The amplifier that they designed is having input referred noise of 52.5uV/sqrt(Hz), power consumption of 850uW, supply voltage of 3.3V dual supply. They used this amplifier in the 4 channel EEG system.

Chon Teng Ma, Pui In Mak, Mang-I Vai, Peng-Unmak(2009) introduced a novel architecture of readout front end biopotential amplifier with low power and low noise which is designed in 90nm CMOS process. The amplifier is designed with both AC coupling and chopper technique which are very essential for improving the CMRR, decreasing the flicker noise and removal of DC offsets. The designed amplifier is having input referred noise of 60.2nV/sqrt(Hz), CMRR of 140dB, power consumption of 16.55uA and supply voltage of 3V.

Xiaodan Zou, Xiaoyuan Xu, Libin Yao, Yong Lian(2009) introduced the designing of low noise amplifier with tunable bandpass filter. Tunable pseudo resistor technique is used to decrease the distortion and to increase the dynamic range[18]. This amplifier is designed in the 0.35um CMOS process with an input

referred noise of 2.5uVrms, programmable gain of 45.6dB to 60dB, frequency of operation from 4mHz o 292Hz,power supply of 1V.

Hai Zhang, Yajie Qin, Zhiliang Hong(2009) proposed the novel low power biopotential amplifier which uses a tunable band pass filter. For making the gain and bandwidth programmable a T-switch with high cutoff pseudo resistor is used to eliminate the low frequency distortions. This is designed in 0.18um CMOS process with supply voltage of 1.8V, power consumption of 770nW, bandwidth of 193Hz to 407Hz, gain of 41.5dB to 62dB, input referred noise of 3.7uV/sqrt(Hz).

M. Chae, J. Kim and W. Liu (2008) presented a bio-potential amplifier designing which used a full differential self -biased operational amplifier with miller capacitance technique. Using this technique they measured the various biopotential signal and showed how the parameters of biopotential amplifier are effecting.

Refet Firat Yazicioglu, Patrick Merken, Robert Puersand Chris Van Hoof (2007) describes that in the market there is a very high demand of the biopotential amplifier having the characteristics of low power, small size. While designing any bio-potential acquisition system role of biopotential amplifier is very important. The proposed amplifier i.e AC-COUPLED CHOPPED INSTRUMENTATION AMPLIFIER is useful for acquiring any type of biopotential signals like EEG, ECG, EMG. With the help of this amplifier CMRR can be increased and electrode offset voltage is reduced.

Reid R Harrison(2007) proposed a biopotential amplifier which is designed using 0.6um CMOS process and the designed amplifier is consisting of 16 fully differential amplifier which is having a gain of 46dB, input referred noise of 2uV/sqrt(Hz) and bandwidth of 10Hz to 10KHz[2].

Benoit Gosselin, Mohamad Sawan, C. Andrew Chapman(2007) proposed the bioamplifier which is useful for the low power applications. When we are designing the bioamplifier for multichannel system then this amplifier is very suitable. Active low frequency suppression technique[3] is used to decrease the size of the amplifier. In the feedback path of amplifier an integrator is used which is helpful for maintaining the high pass cutoff frequency. A large time constant is achieved by using the mos bipolar resistors and integrated capacitors. This amplifier is designed in the 0.18um CMOS process which is having an input referred noise of 5.6Uv/sqrt(Hz), power dissipation of 8.6uW and gain of 50dB.

Jayant Parthasarathy, Arthur G. Erdman, Aaron D. Redish, and Babak Ziaie (2006) introduced a technique to design an integrated biopotential amplifier using a feed-forward DC cancellation topology. While designing any integrated biopotential amplifier a major problem is dc offset voltage that is generated due to the interaction between electrode and electrolyte interface. Due to this DC offset voltage interferences occur in the bio-potential amplifier and it effects the CMRR of the amplifier. He designed a circuit in such a way that input signal passed through two paths as the amplitude and phase characteristics of the input and the dc offset signal is different. So at the output DC signal is subtracted from the input signal. So to implement this first they designed a first order low pass filter and then this signal is subtracted from the input signal to get our desired input which is free from the DC offset voltage.

Xiongfei Meng, Karim Arabi, Resve Saleh(2006) proposed the methods for designing of decoupling capacitors. These decoupling capacitors are used for reducing power supply noise. When they designed it in 90nm CMOS process there are some problems regarding the electrostatic discharge . So to eliminate that they proposed a cross coupled design.

Reid R Harrison, Cameron Charles (2003) introduces the bio-amplifier for neural recording applications in 1.5um process.They used a MOS bipolar pseudo resistor element in there circuit for the amplification of the low frequency signals. Here they mainly concentrated to design the amplifier having low power and low noise. So in there design they made all the transistors to work in saturation and sub-threshold region. With MOS bipolar pseudo resistor element we can amplify the low frequency signals by decreasing the cutoff frequency. As the cutoff frequency is inversely proportional to the time constant RC. With increase in resistance RC time constant will increase and cutoff frequency will decrease. So it is very crucial element in the bioamplifier designing.

CHAPTER 3

PROPOSED WORK

Fig.2 shows the schematic of proposed ultra low power bioamplifier with feedback circuitry. In this paper, main concern is to design circuit with ultra low power consumption, transistors are preferred to be operate in weak inversion region. Sizing of transistors is a crucial parameter for achieving the desired functionality. PMOS input differential pair is used instead of NMOS because flicker noise content in PMOS device is much smaller in comparison with NMOS device. For reduction of 1/f noise PMOS device dimensions are made larger and for ultra low power applications sizing of transistors is crucial parameter. In the proposed low power bioamplifier two input capacitors C_1, C_2 and feedback capacitor C_f are used to set midband gain.

As shown in Fig.2, a load capacitor C_L is used to compensate the circuit. Increase in feedback capacitance results in low cut off frequency but it is having disadvantage of consuming large chip area, so a standard value is used according to the requirement.

$$A_V \quad \frac{C_1}{C_f} \qquad (3.1)$$

Here A_V is the midband gain. MOS-bipolar pseudo resistors along with feedback and input capacitors are used for filtering purpose such that circuit amplifies signals in a particular frequency range.

Input referred noise of the amplifier is given by the sum of thermal noise and flicker noise. Thermal noise is due to the collision of electrons in the channel of MOS transistor and thermal noise is dependent upon the temperature. From noise analysis following equation represents the input thermal noise.

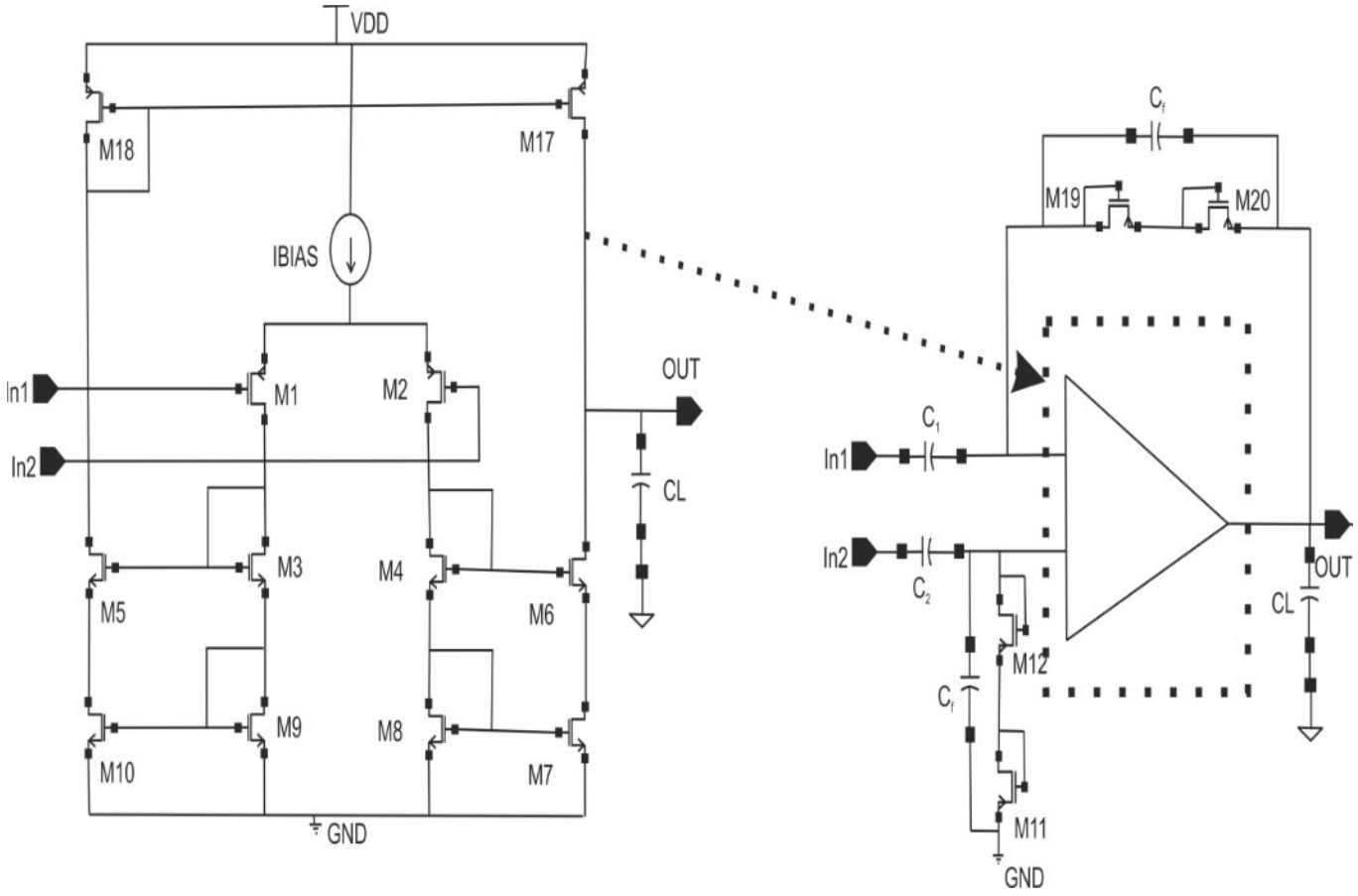

Figure.3.1 Proposed bioamplifier architecture

$$I_n^2 \quad 4kT\gamma g_m$$

$$V_n^2 \quad I_n^2 r_o^2$$

$$V_{ni,thermal} \quad \frac{4kT\gamma}{g_{m1}}\left[1+\frac{2g_{m3}}{g_{m1}}+\frac{2g_{m7}}{g_{m1}}+\frac{g_{m18}}{g_{m1}}\right] \qquad (3.2)$$

$V_{ni,thermal}$ = Input thermal noise of bioamplifier, T= Operating temperature, k= Boltzmann constant, γ= Coefficient which value is 2/3 for long channel devices and larger value for submicron devices.

In MOSFET between the oxide layer and the silicon substrate a special phenomena arises where some dangling bonds are formed on the silicon substrate, which results in extra energy states. So when charge carriers cross these bonds some of the charge carries are trapped and released later. This results in the flicker noise in the overall circuit. Generalized formula for the flicker noise is given by

$$V_n^2 \quad \frac{k}{C_{ox}W.L} \cdot \frac{1}{f} \qquad (3.3)$$

From the equation(3) it is clear that flicker noise is independent of the temperature and the biasing current. Flicker noise is also called as the 1/f noise and it generally occurs at the lower frequencies. It is inversely proportional to the WL , so when we are designing a circuit for low noise applications aspect ratios of transistors generally made larger. Flicker noise content in PMOS devices is less in comparison with the NMOS devices. For bioamplifier designing PMOS differential input pairs are used with high aspect ratios to decrease the flicker noise.

From the equation (2) it shows, to reduce input thermal noise gm1 should be as high as possible in comparison with g_{m3}, g_{m7}, g_{m18}. Though transconductance and (W/L) are directly proportional to each other, higher transconductance is achieved by enhancing aspect ratios of transistors. Aspect ratios of M1 and M2 denoted as $(W/L)_1$, for transistors M_3-M_6, $(W/L)_3$ represents width to length ratio, $(W/L)_7$ and $(W/L)_{18}$ represents aspect ratios of M_7-M_{10} and M_{17}, M_{18} respectively. Increase in $(W/L)_1$ enhance the gm1 value and according to equation(2) input thermal noise decrease as a result of increase in gm1. As the Input thermal noise is directly proportional to g_{m3}, g_{m7}, g_{m18}, it can be minimized by reducing these transconductance values. For reducing these transconductance values $(W/L)_3$, $(W/L)_7$, $(W/L)_{18}$ should be minimized and as aspect ratios are minimized arbitrarily then internal capacitances associated with these starts decreasing and finally affects dominant pole frequency. Due to all these consequences phase margin gets distorted.

$$NEF \quad V_{ni,thermal}\sqrt{\frac{2I_{total}}{\pi.U_T.4kT.BW}} \qquad (3.4)$$

$$U_T \quad \frac{kT}{q} \qquad (3.5)$$

In designing of bioamplifier for ultra low power applications noise gets affected because power and noise are inversely proportional to each other. For reducing noise in circuit input PMOS differential pair dimensions are made larger but increase in aspect ratios lead to higher power consumption. So a tradeoff arises between power consumption and input noise which is determined by NEF. NEF is given by equation(6). U_T represents thermal voltage, k is the coupling coefficient(0.7). Ideal value of NEF is one but practically it is difficult to achieve that value. The aspect ratios of the proposed bioamplifier is given in Table I.

TABLE I Transistors aspect ratio of proposed biopotential amplifier

Device	Ratio(W/L)μm
$M_1 - M_2$	200/1
$M_3 - M_{10}$	6/20
$M_{17} - M_{18}$	3.2/6.4
$M_{17} - M_{18}$, $M_{19} - M_{20}$	1/0.18

As shown in Fig.2(a) feedback is consisting of four MOS bipolar pseudo resistors instead of resistor for getting higher time constant as a result reduction in low cutoff frequency[1].

$$f_c \quad \frac{1}{2\pi RC} \qquad (3.6)$$

When negative Vgs is applied to these devices they act as the diode connected PMOS transistors. Performance of pseudo resistors can be enhanced by using fixed dc voltage diode connected PMOS transistor and current source amplifier for setting the required dc voltages. Simple MOS-bipolar pseudo resistors are used to avoid the complexity, while using these devices high resistance in the range of tera ohms is attained. In the proposed architecture due to the transistors M_7-M_{10} power consumption is decreased to some extent, which is very low as compared to the bioamplifiers proposed in the previous paper[5],[13],[14]. When feedback is applied to OTA it amplifies signals at a selected frequency range.

3.1 OPERATION OF BIOAMPLIFIER USING DIFFERENT CURRENT MIRROR CONFIGURATIONS

For the proposed bioamplifier OTA, analysis is done using simple current mirror, cascode current mirror and Wilson current mirror configurations and it's effect to gain, power consumption, input referred noise and bandwidth is discussed. Power consumed by current mirror configuration is wasted as they are only meant for the generation of current. While designing bioamplifier circuit, power consumption can be reduced by using efficient biasing circuitry.

Simple current mirror exhibits lower output resistance. Bioamplifier constructed using this current mirror for constant current source, current in micro amperes range is distributed to rest of circuitry. When transistors are working in strong inversion region current in circuit increases linearly, while in weak inversion region current increases exponentially. Two input PMOS differential pair is sized with large dimensions to overcome the problem of high input referred noise. Current mirror used in bioamplifier circuit is having aspect ratios of $(W/L)_{9\text{-}10}$ =10/10.

As in the circuit, current in microampere range is flowing some transistors are working in the weak inversion region and some are in strong inversion region. Using simple current mirror configuration a large low cutoff frequency and a reasonable bandwidth is achieved. Input referred noise is also affected by using different current mirror configurations by a small value. Designed circuit results in a midband gain of 45 dB which amplifies signals in the frequency range of 30 Hz to 6.71 KHz. The circuit consumes 42 uW of power with an input referred noise of 1.53 uV/sqrt(Hz). The schematic of the bioamplifier using simple current mirror is shown in the Figure.3.

Cascode current mirrors are having higher output resistance in comparison with simple current mirror. Input transistors are operating in weak inversion region providing a higher transconductance value such that input referred noise of the circuit is small. Power consumption of bioamplifier is reduced while gain and input referred noise of circuit remained approximately equal in comparison with bioamplifier using simple current mirror. Bioamplifier is having a high pass frequency of 31.7 Hz and low pass frequency of 3.51 KHz. Transistors aspect ratios of cascode current mirror used in bioamplifier are as follows $(W/L)_{10}$, $(W/L)_{16}$=10/10 and $(W/L)_{9}$, $(W/L)_{15}$=20/2.

Wilson current mirrors provide higher output resistance in comparison with both the simple and cascode current mirror configurations. So this distribution of current enable the transistors to operate in weak inversion region. This current mirror configuration provides better low cutoff frequency value in comparison with simple and cascode current mirror configuration. Bioamplifier using Wilson current mirror for biasing provides a midband gain of 45.38 dB, input referred noise of 1.8 uV/sqrt(Hz), low pass frequency of 5.02 Hz and high pass frequency of 2.927 KHz and ultra low power consumption of 6.25 uW. Transistors aspect ratios of Wilson current mirror used in bioamplifier are as follows (W/L)10, (W/L)16=10/10 and (W/L)9, (W/L)15=20/2. Fig.5 shows the graph of relationship between input and output currents of simple, cascode and Wilson current mirror. Wilson current mirror is providing low output currents to OTA in comparison with simple and cascode current mirror and it is having high linearity as compared to rest two configurations.

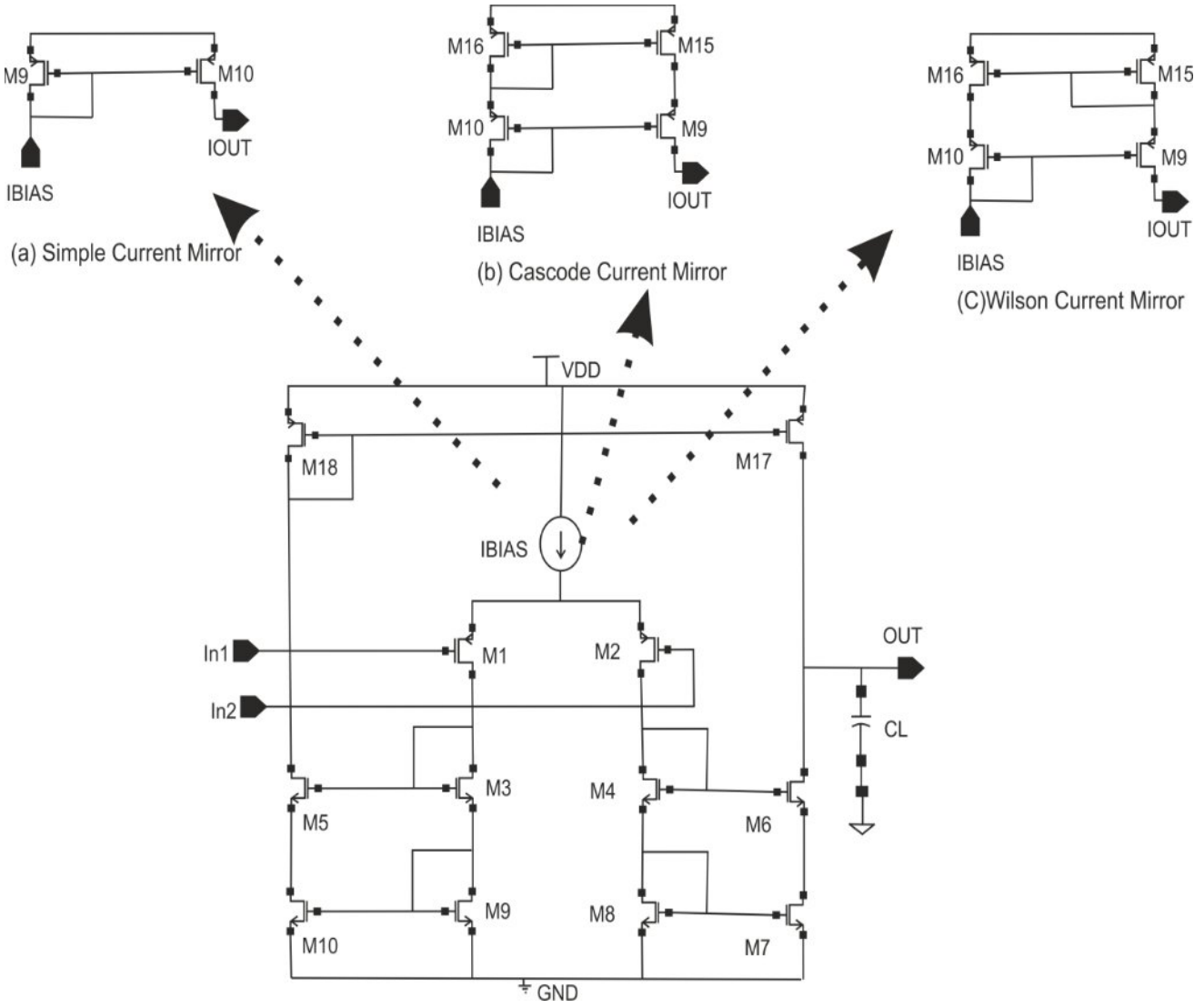

Figure. 5.2 Proposed bioamplifier architecture with simple, cascode and Wilson current mirror

CHAPTER 4

RESULTS AND DISSCUSSIONS

Proposed OTA used in bioamplifier circuitry is providing a gain of 57 dB and phase angle of 57 deg as shown in Figure.4.1. To avoid distortion at output, phase angle of an amplifier should be in between 45 deg to 60 deg. Measured input referred noise is 1.59 uV/sqrt(Hz) and the corresponding graph is shown in Figre.4.2. OTA consumes 6.24 uW of power. When the RC feedback is applied to the circuit as shown in Fig.2 only the selected frequency range is amplified, performing the operation of a band pass filter.

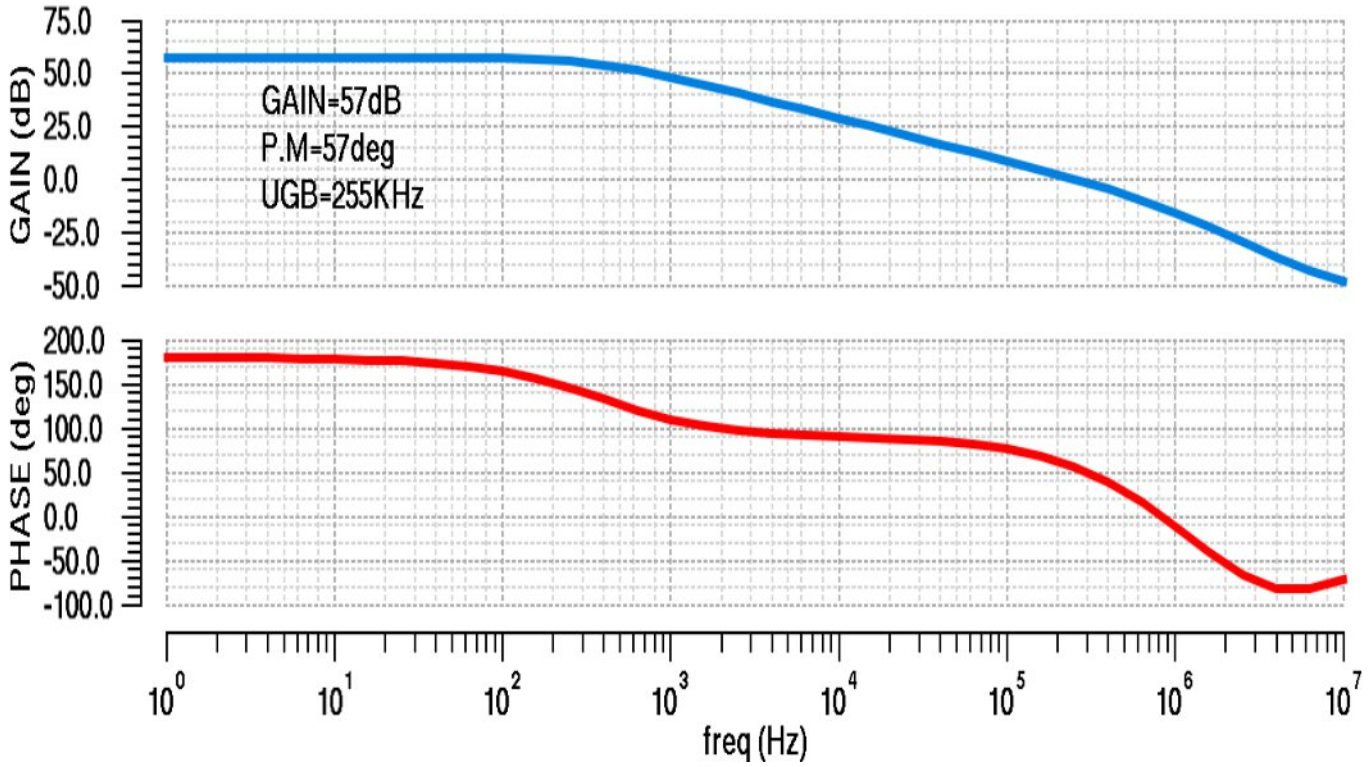

Figure.4.1 Gain and Phase plot of proposed OTA in bioamplifier circuit

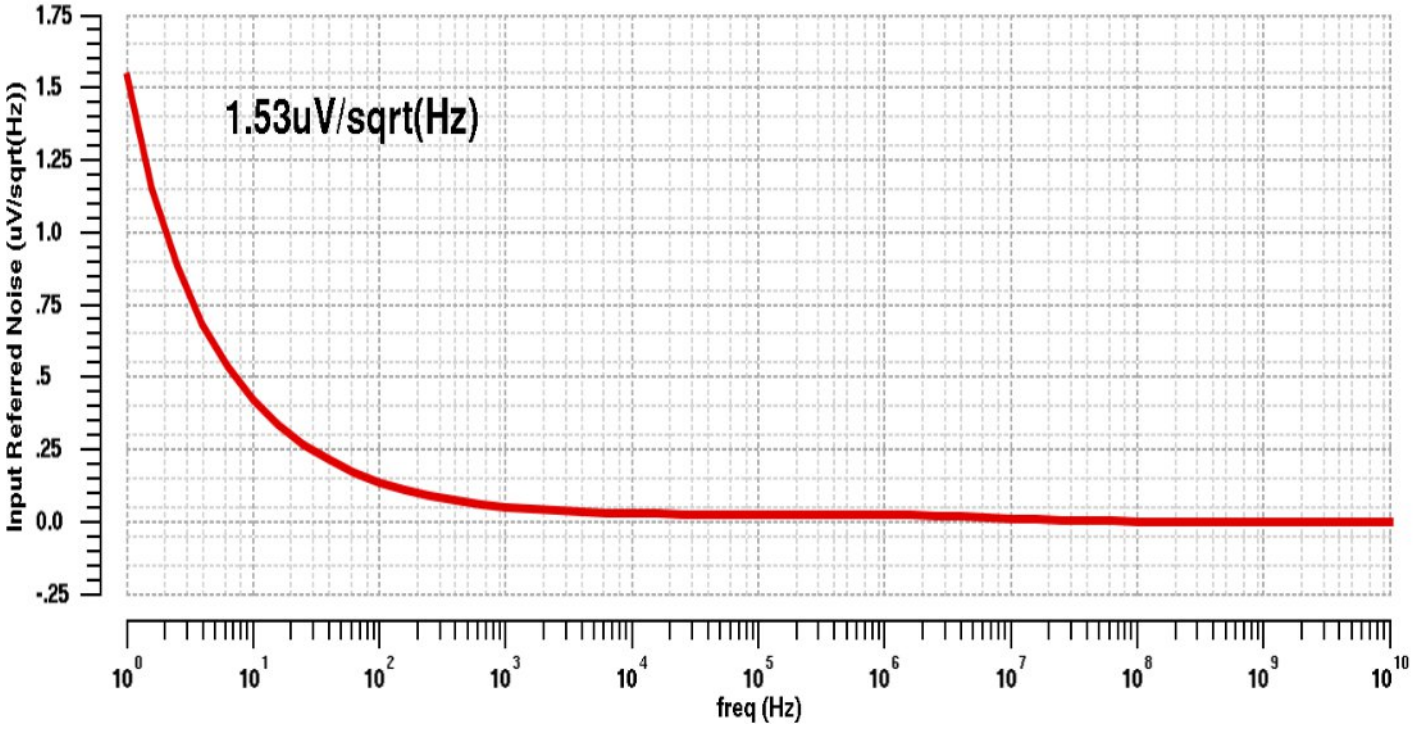

Figure.4.2 Input Referred Noise plot of OTA in bioamplifier circuit

4.1 BIOAMPLIFIER USING SCM FOR BIASING:

Figure.4.3 shows the measured midband gain of bioamplifier with simple current mirror. Measured midband gain value is 45 dB, amplifying signals in the frequency range of 30 Hz to 7 KHz. Low cutoff frequency of 30 Hz is achieved due to the use of MOS-bipolar pseudo resistors in feedback circuit. Circuit is consuming 42 uW of power for the proper operation. Figure.4.4 shows the measured Input referred noise of 1.52 uV/sqrt(Hz) for bioamplifier circuit. The circuit is having a bandwidth of 6.97 KHz. Figure.4.5 shows the CMRR of the bioamplifier and CMRR (common mode rejection ratio) of greater than 48 dB is achieved for the bioamplifier using simple current mirror for biasing. PSRR(power supply rejection ratio) of greater than 69 dB is attained as shown in Figure.4.6. PSRR is defined as the rejection capability of the any circuit to the noise generated in the power supply lines and PSRR is given by the following equation :

$$PSRR(dB) \quad 20\log_{10}\left(\frac{\Delta V_{sup\ ply}}{\Delta V_{out}}.A_v\right) \qquad (4.1.1)$$

$$PSRR(dB) \quad 20\log_{10}\left(\frac{\Delta V_{out}/\Delta V_{in}}{\Delta V_{out}/\Delta V_{sup\ ply}}\right) \qquad (4.1.2)$$

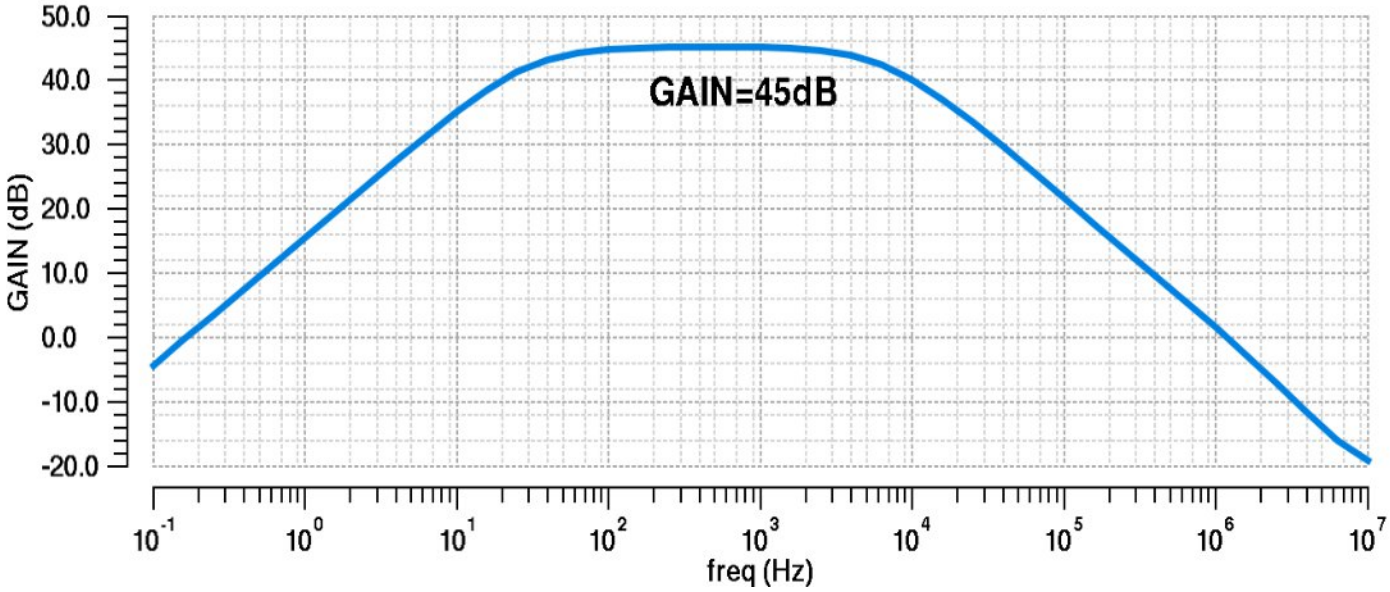

Figure.4.1.1 Gain plot of bioamplifier using SCM configuration

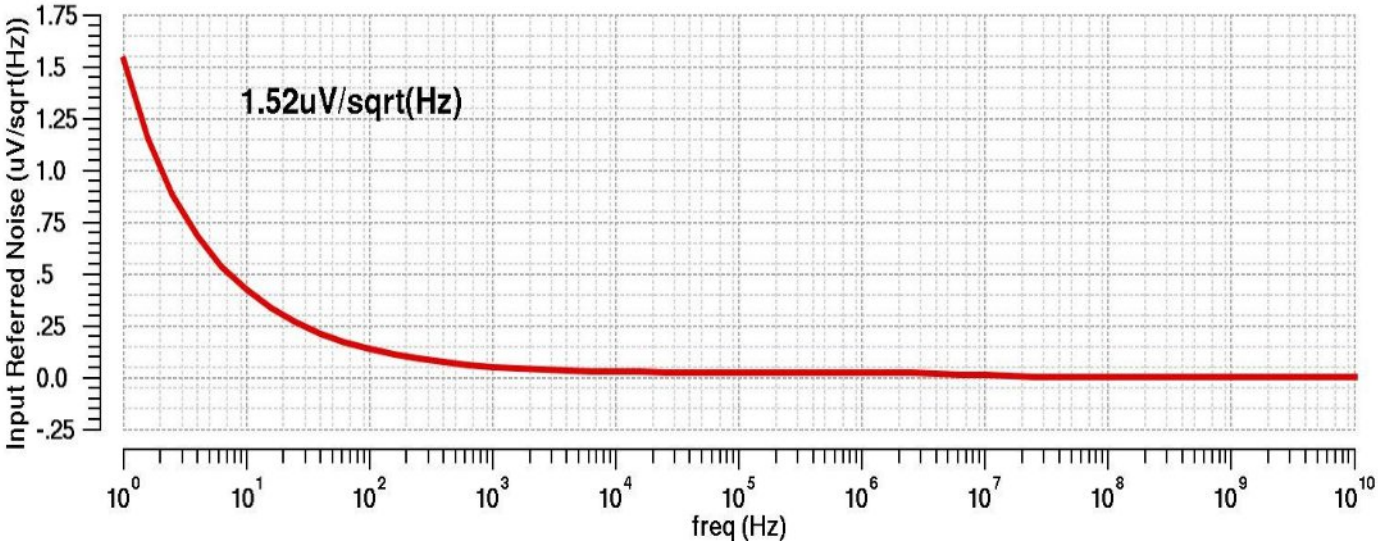

Figure.4.4 Input Referred Noise plot of bioamplifier using SCM configuration

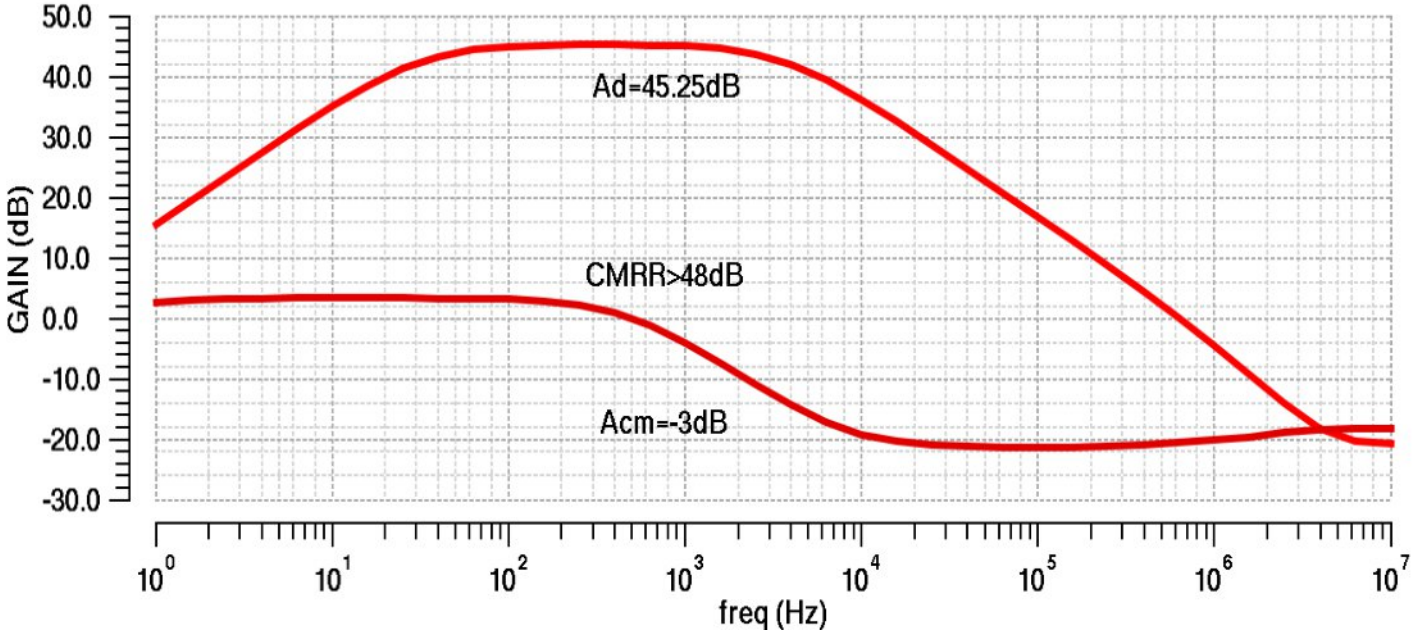

Figure.4.5 CMRR plot of bioamplifier using SCM configuration

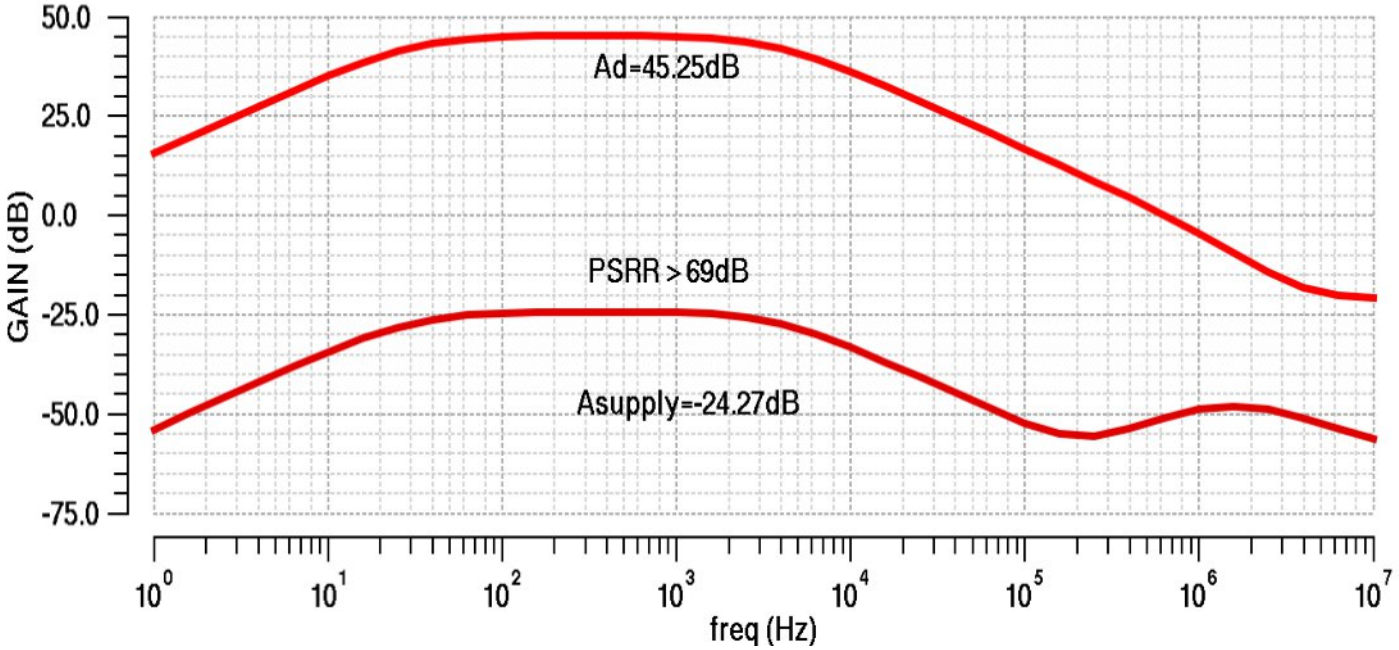

Figure.4.6 PSRR plot of bioamplifier using SCM configuration

4.2 BIOAMPLIFIER USING CCM FOR BIASING:

Figure.4.7 shows the gain plot of bioamplifier using cascode current mirror. A midband gain of 45.38 dB is achieved, amplifying signals in the frequency range of 31.7 Hz to 3.51 KHz. This circuit is operating by consuming 20 uW of power, with an input referred noise of 1.66 uV/sqrt(Hz) as shown in Figure.4.8. Circuit is having a bandwidth of 3.47 KHz. CMRR and PSRR plots of bioamplifier is shown in Figure.4.9 and Figure.4.10. This configuration resulted in better CMRR and PSRR values in comparison with SCM configurations. CCM configuration provides CMRR around 50 dB and PSRR around 70 dB.

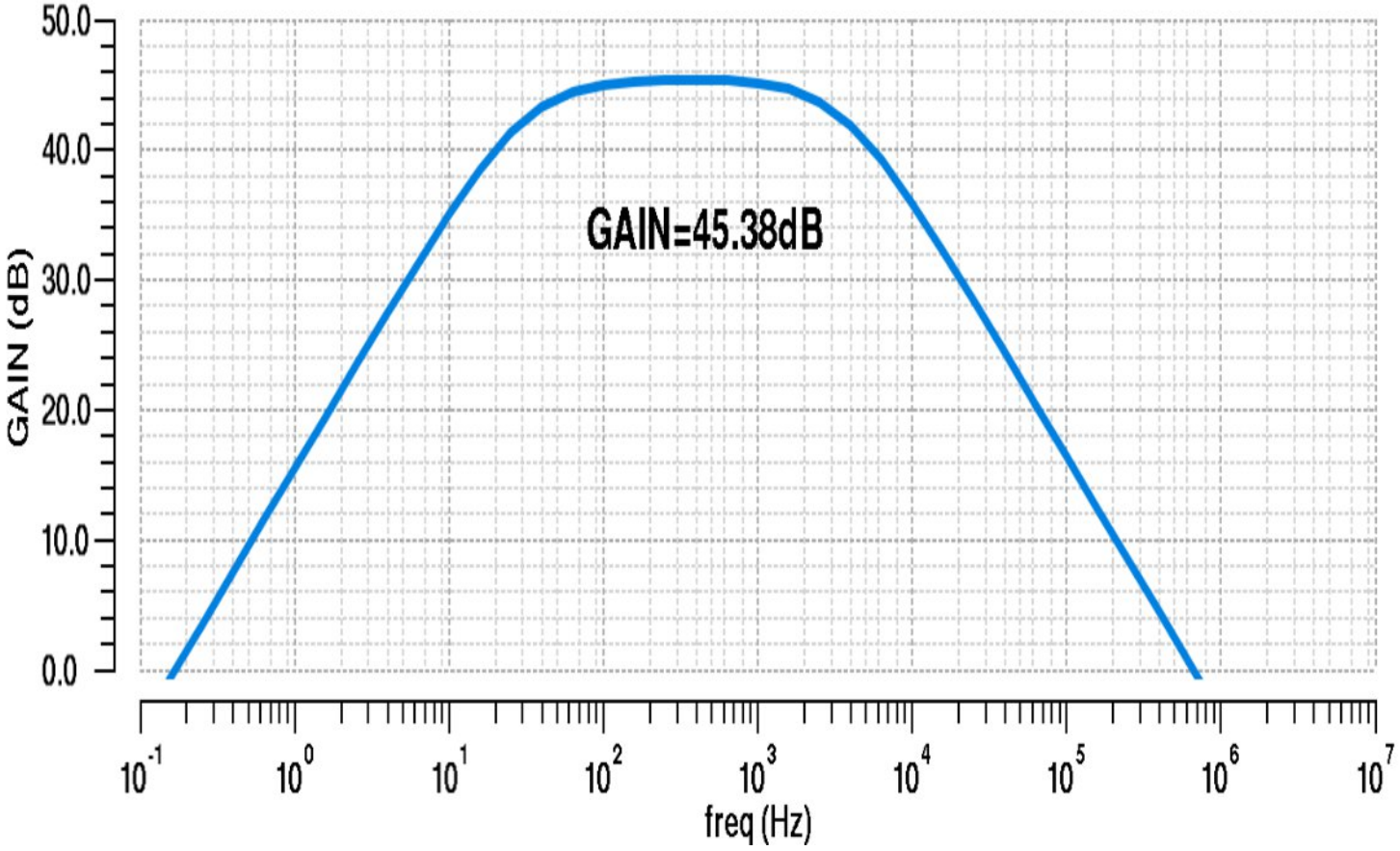

Figure.4.2.1 Gain plot of bioamplifier using CCM configuration

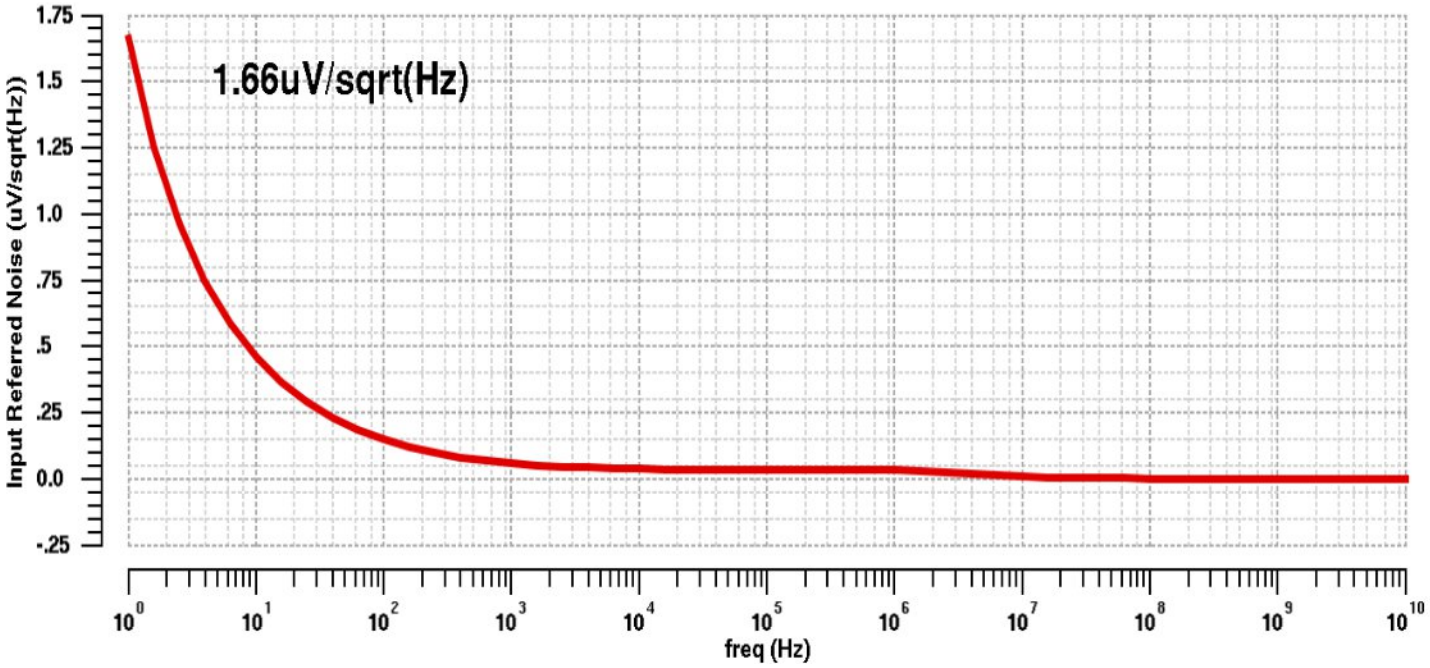

Figure.4.2.2 Input Referred noise of bioamplifier using CCM configuration

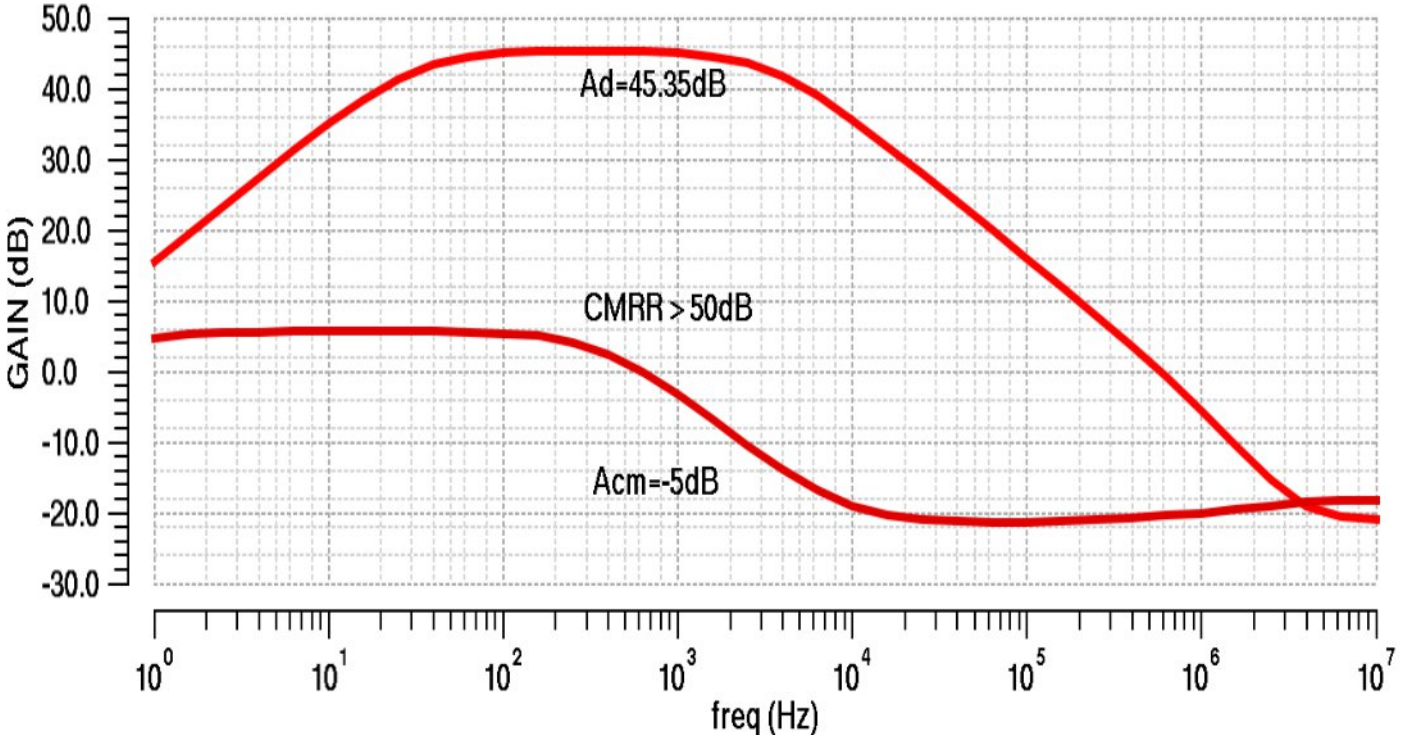

Figure.4.2.3 CMRR plot of bioamplifier using CCM configuration

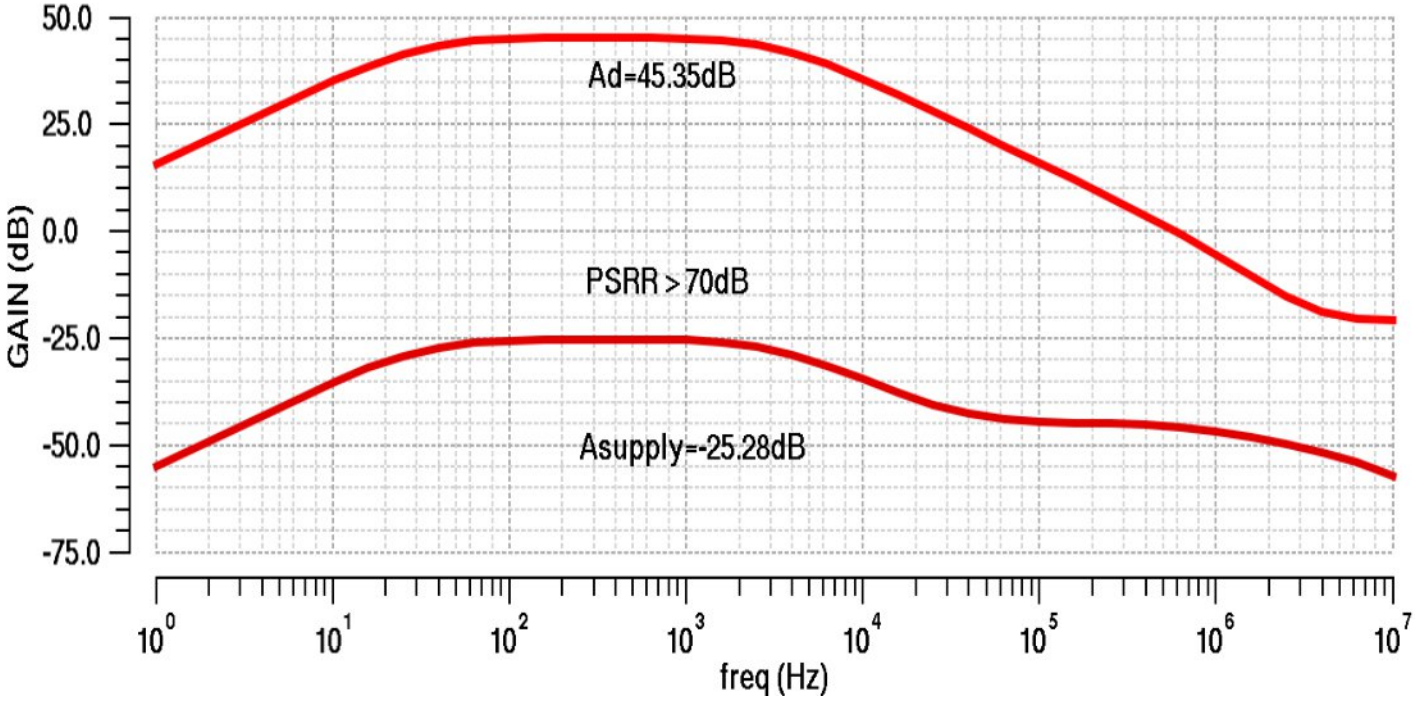

Figure.4.2.4 PSRR plot of bioamplifier using CCM configuration

4.3 BIOAMPLIFIER USING WCM FOR BIASING:

Figure.4.3.1 shows the simulated results of bioamplifier using Wilson current mirror, providing a midband gain of 45.38 dB, amplifying signals in the frequency range of 5.02 Hz to 2.927 KHz. The bioamplifier with WCM configuration is consuming a power of 6.25 uW, which is very less in comparison with amplifiers proposed in previous works. Proposed one is having input referred noise of 1.8 uV/Sqrt(Hz) as shown in Figure.4.3.2 and bandwidth of 2.9 KHz. Bioamplifier with WCM configuration is providing efficient CMRR as well as PSRR values. Bioamplifier resulted in CMRR of grater than 68 dB and PSRR of greater than 76 dB as shown in Figure.4.3.3 and Figure.4.3.4 respectively.

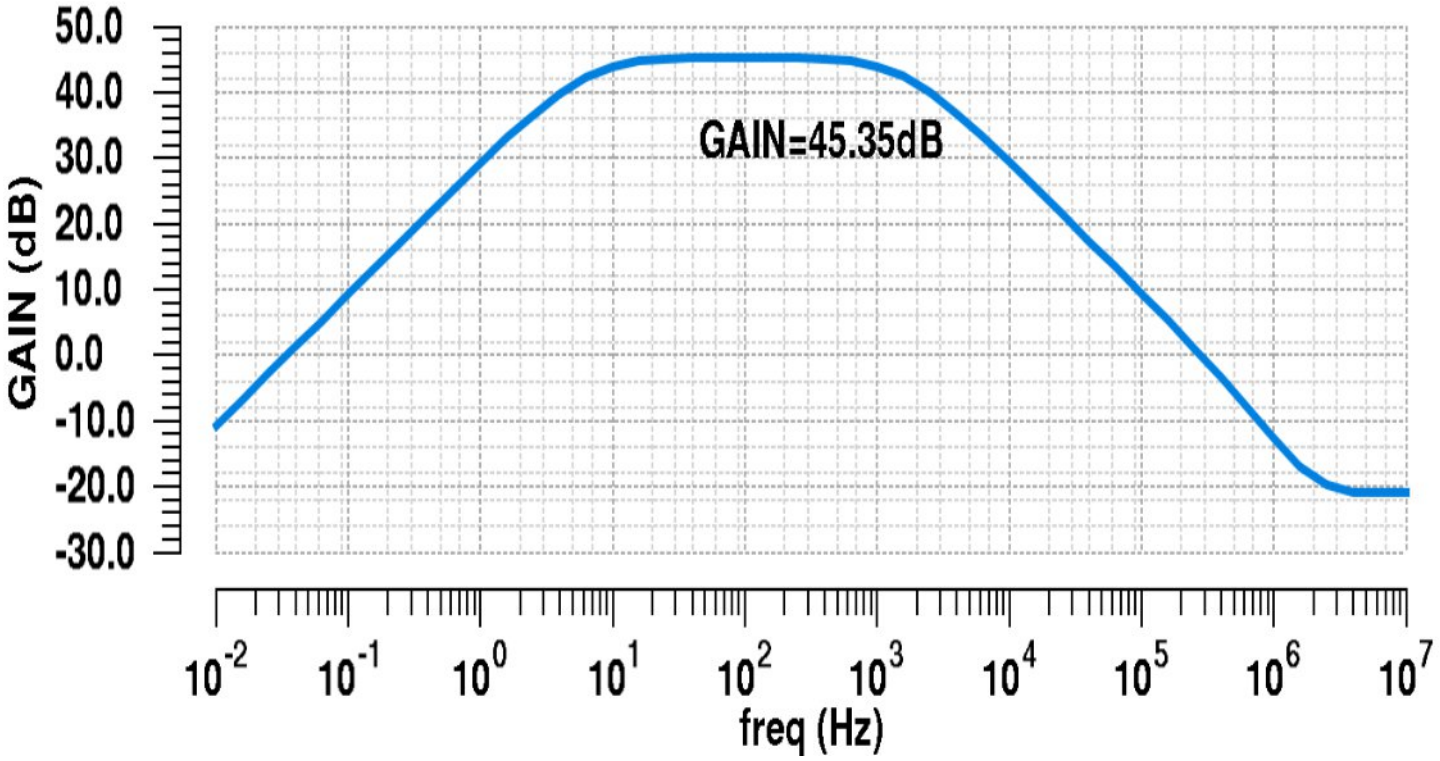

Figure.4.3.1 Gain plot of bioamplifier using WCM configuration

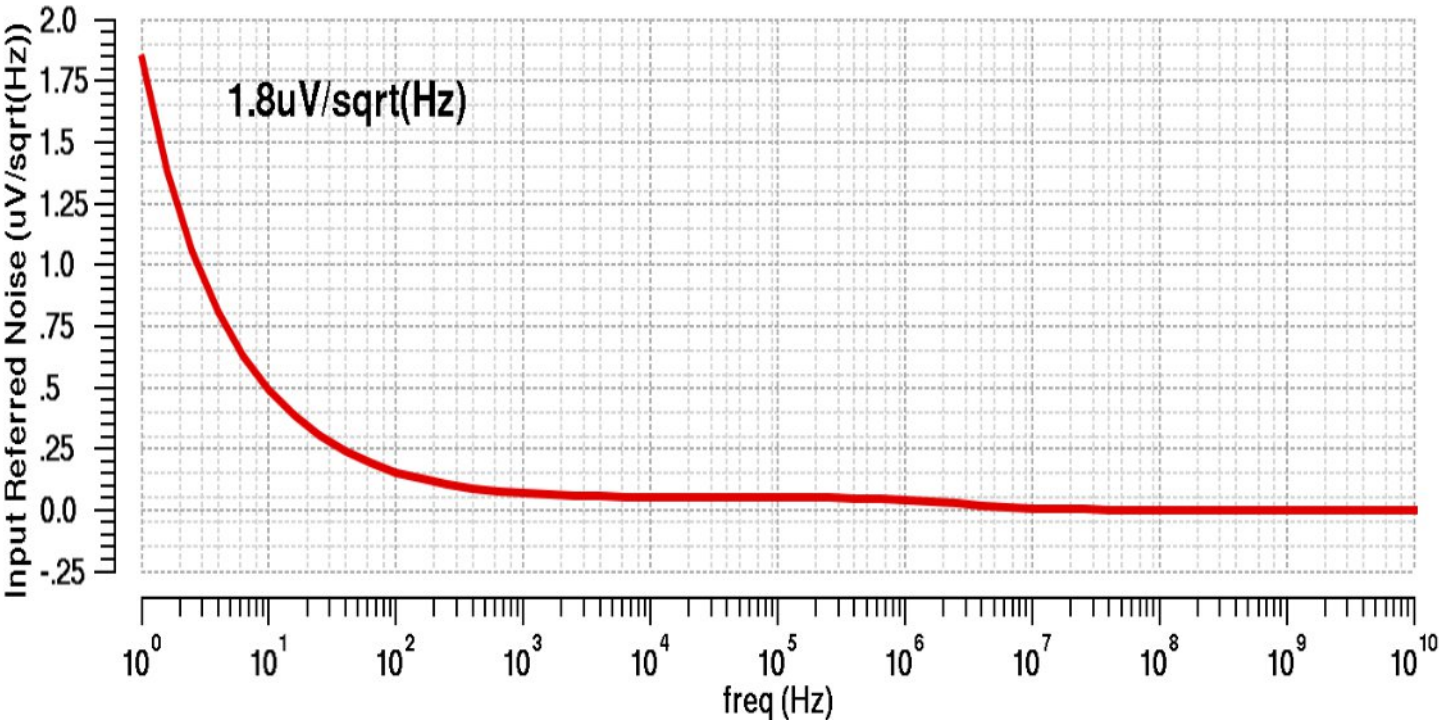

Figure.4.3.2 Input Referred noise plot of bioamplifier using WCM configuration

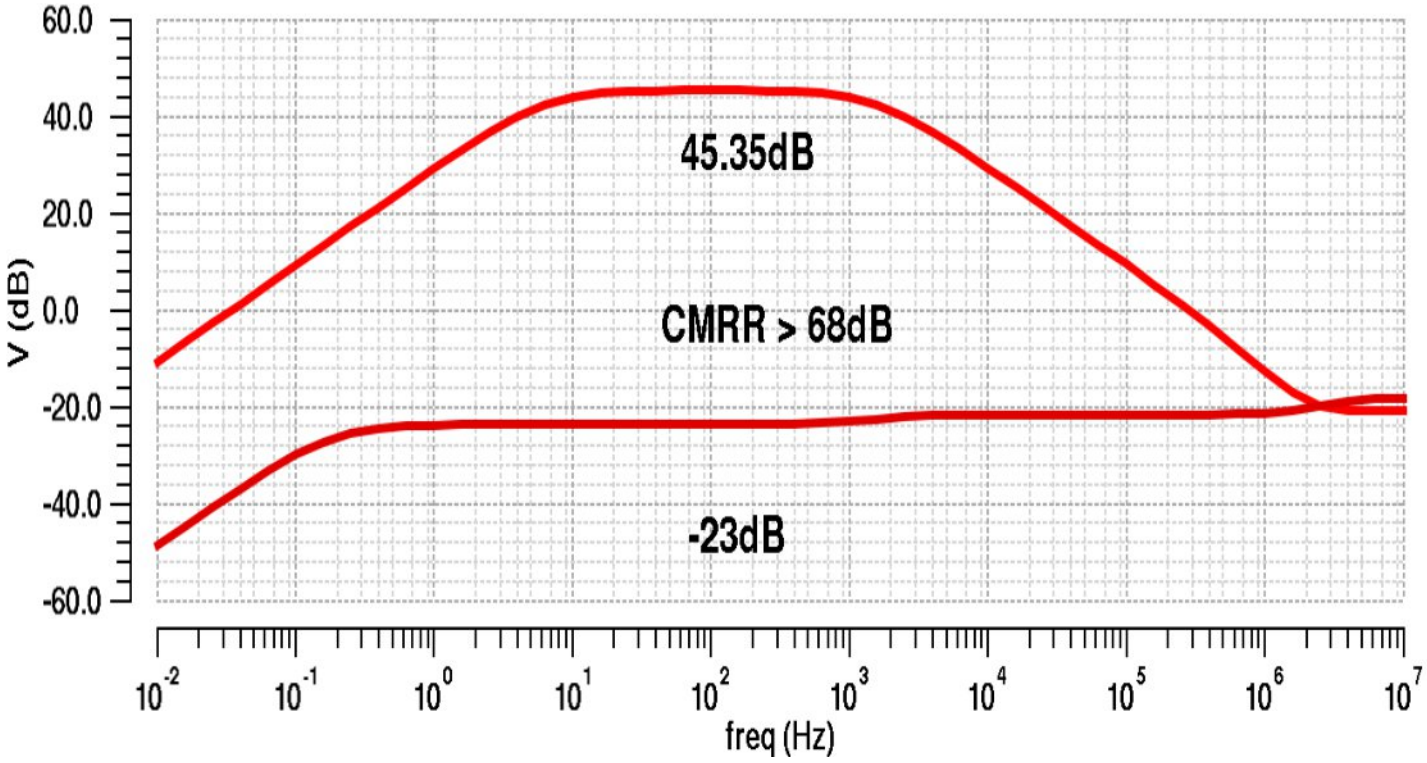

Figure.4.3.3 CMRR plot of bioamplifier using WCM configuration

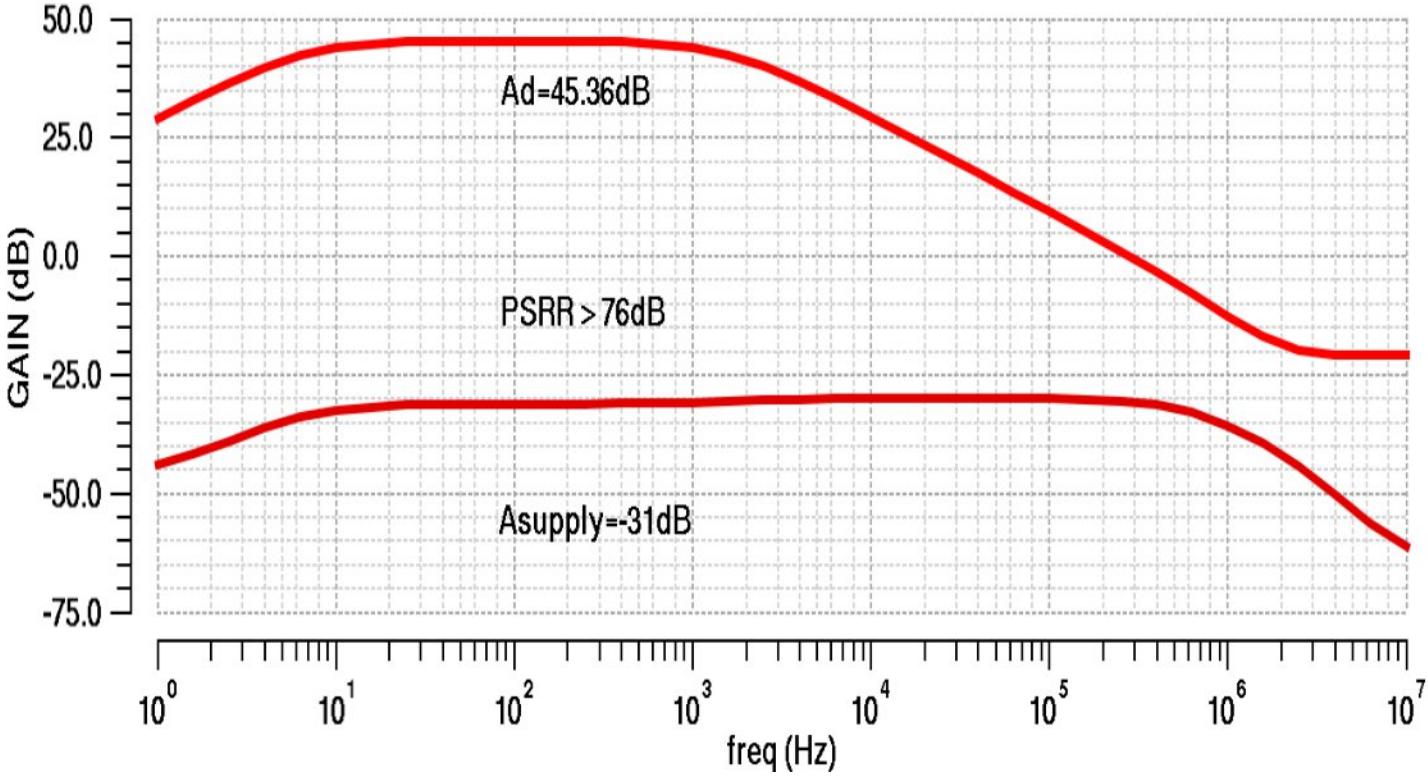

Figure.4.3.4 PSRR plot of bioamplifier using WCM configuration

4.4 COMPARISON OF SCM, CCM, WCM CONFIGURATIONS:

From the above discussion a comparison is made among all these configurations, some important points are noted below. Bioamplifier using SCM configuration consuming more power and higher lower cutoff frequency in comparison with the WCM configuration. Though in the WCM configuration bandwidth is decreased in comparison with SCM configuration, WCM configuration is having a better lower cutoff frequency of 5.02 Hz. When SCM is replaced with CCM in bioamplifier, gain remains same and having a better bandwidth as compared to the WCM configuration, but it is having a shortcoming of very high power consumption and higher lower cutoff frequency. Instead of CCM when WCM is used approximately similar gain is achieved, but there is a large difference in power consumption which is very less in comparison with cascode and simple current mirror circuit and WCM configuration is having better low cutoff frequency in comparison with SCM and CCM configurations. When these three current mirror configurations are used for biasing bioamplifier no significant difference arises in input referred noise value of the circuits. Bioamplifier with WCM configuration results in better CMRR and PSRR values in comparison with SCM and CCM.

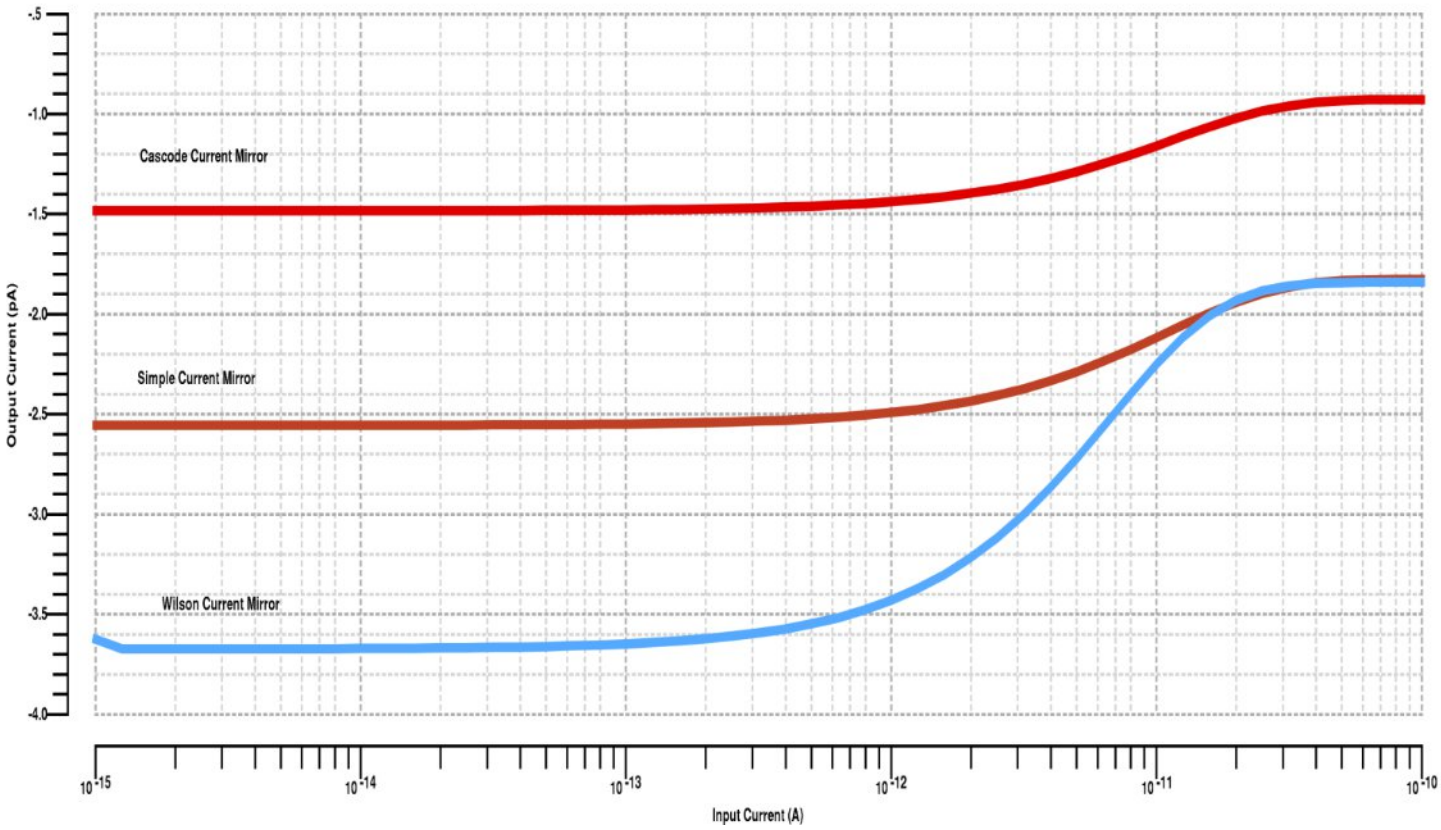

Figure.4.4.1 Graph showing comparison of output currents verses input currents in SCM, CCM, WCM configurations

Figure.4.4.1 shows the graph of relationship between input and output currents of simple, cascode and Wilson current mirror. Wilson current mirror is providing low output currents to OTA in comparison with simple and cascode current mirror and it is having high linearity as compared to rest two configurations.

Figure.4.4.2 shows the relationship of output voltage verses output currents of SCM, CCM and WCM configurations. Graph shows that at 1mv of output voltage SCM is having output current of 7.8 µA, CCM is having 3.8 µA and WCM output current is at 1.6 µA. So Wilson current mirror is operating at low output current levels in comparison with SCM and CCM. Due to this reason bioamplifier with Wilson current mirror configuration resulting in low power consumption in comparison with SCM and WCM.

In proposed circuit WCM configuration is preferred as this configuration providing better results in comparison with SCM and CCM. A comparison table is shown in Table II for the SCM, CCM and WCM configurations.

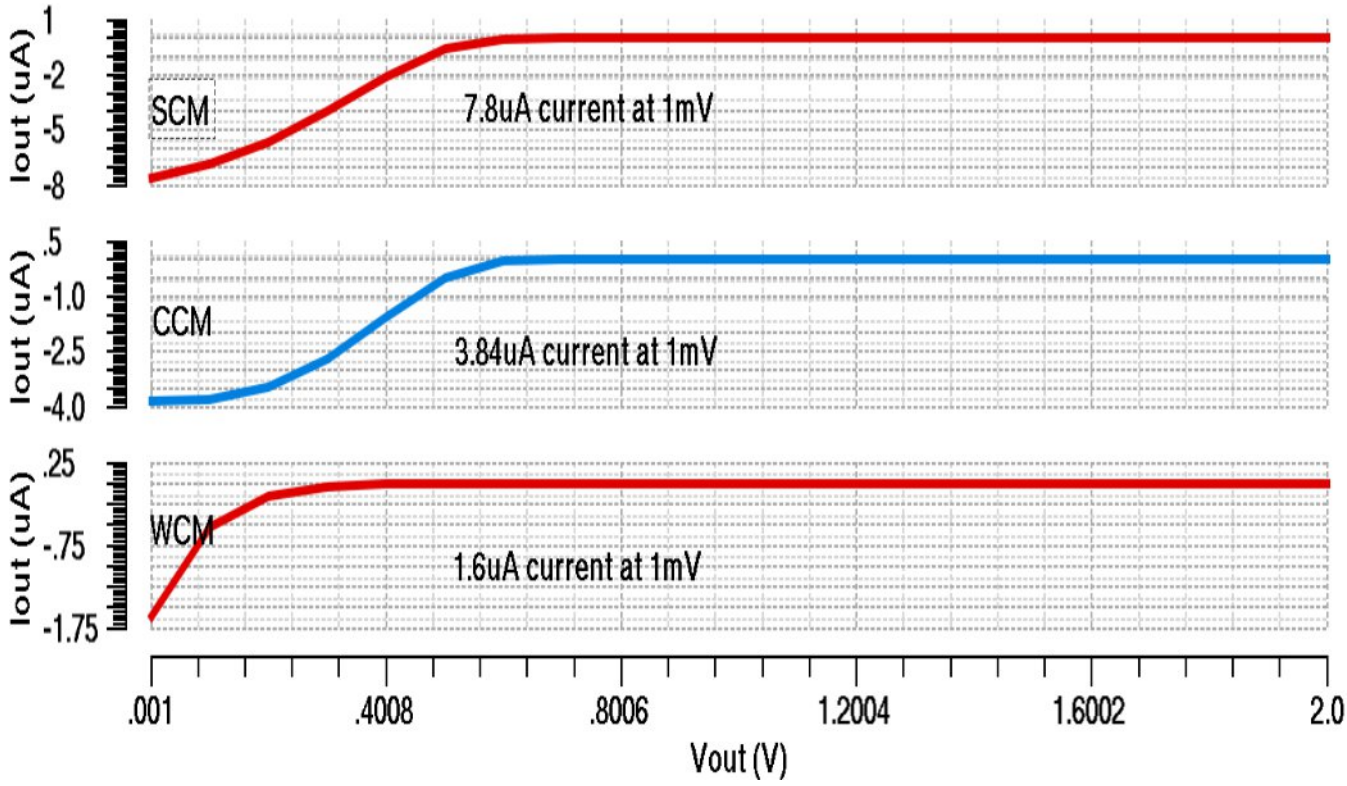

Figure.4.4.2 Graph showing comparison of output current versus output voltage in SCM, CCM, WCM

TABLE II. Comparison of the proposed biopotential amplifier circuit with SCM, CCM and WCM biasing configurations

Specifications	SCM	CCM	WCM
Gain(dB)	45	45.38	45.38
Power(μw)	42	20	6.25
Input Referred Noise (μv/sqrt(Hz))	1.53	1.66	1.8
Frequency Range	30Hz-7KHz	31.7Hz-3.51KHz	5.02Hz-2.927KHz
Bandwidth(KHz)	6.97	3.47	2.9
CMRR(dB)	>48	>50	>68
PSRR(dB)	>69	>70	>76

Table III show the comparison of proposed circuit results with the bioamplifier circuits of previous studies. It shows that, the circuit in[1] is having a power consumption of 80 uW and gain of 39.5 dB, while proposed circuit is having specifications of very low power of 6.25 uW and midband gain of 45.35 dB, which are much efficient results than the circuit in[1]. In [13] amplifier operating with a midband gain of 32 dB, BW of 1 KHz, power consumption of 21 uW and input referred noise of 3 uV/sqrt(Hz), while the proposed circuit is having better results for all these specifications in comparison with [13]. In rest of the studies some specifications are better and some are worst in comparison with the proposed one. As in this paper, power consumption is the main attribute the proposed circuit is having lower power consumption in comparison with the rest circuits. The main motive of this paper is to design ultra low power bioamplifier used for implantable and wearable device applications in biomedical field. From the above discussions the proposed one is the most advantageous one for low power applications.

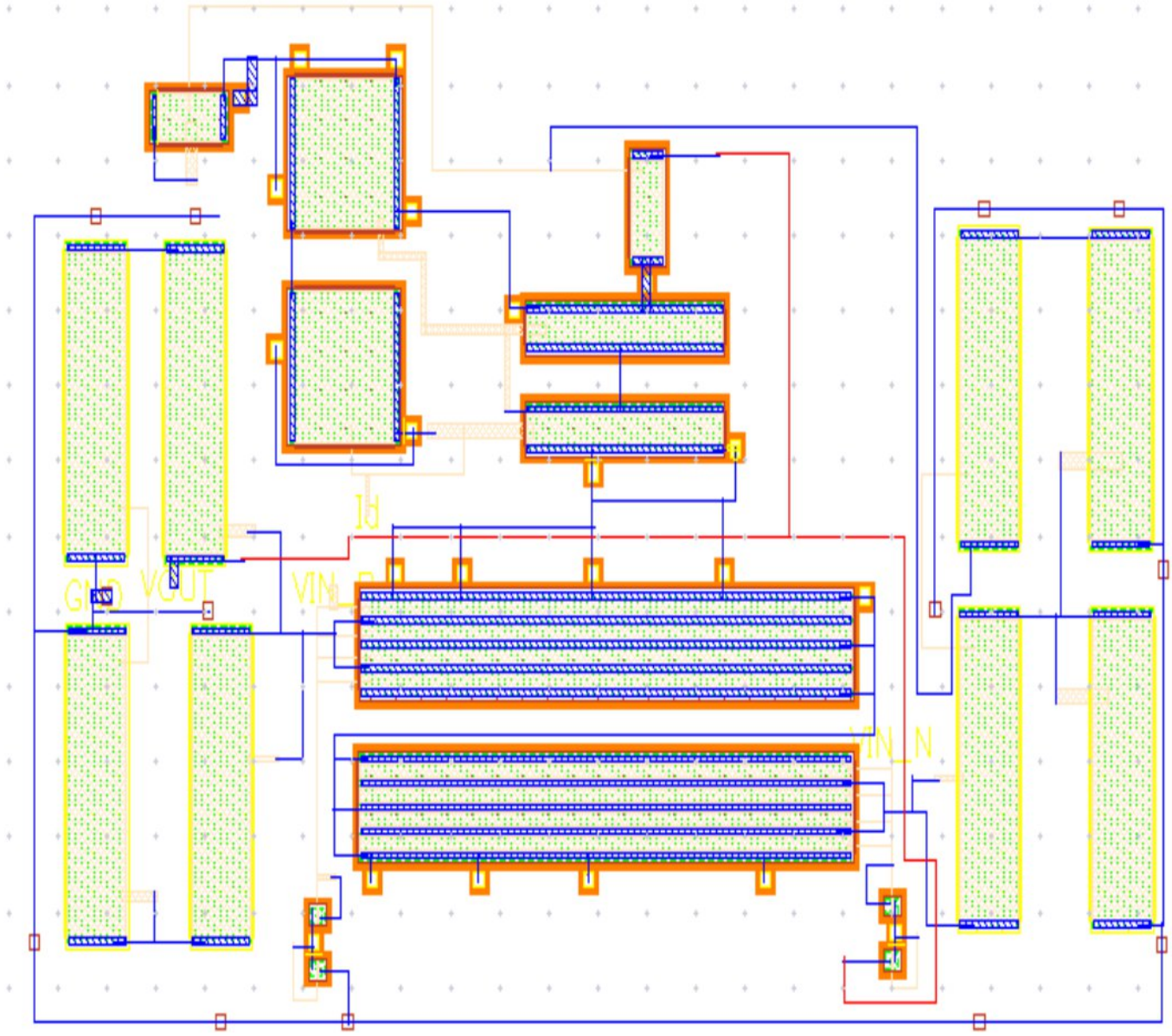

Figure.5 Layout of OTA used in bioamplifier

TABLE III. Comparison of the proposed biopotential amplifier circuit and other existing biopotential amplifiers

References	Gain (dB)	Bandwidth (KHz)	Frequency Range	Power(μw)	Noise(μv/sqrt(Hz))
2003[1]	39.5	7.19	0.02Hz-7KHz	80	2.2
2007[3]	50	8.9	103.4Hz-9.1KHz	8.6	5.6
2007[4]	40.8	5.27	45Hz-5.32KHz	7.56	1.66
2010[5]	70	10	0-10KHz	31	88
2013[13]	32	1	…….	21	3
Proposed Circuit	45.38	2.9	5.02Hz-2.927KHz	6.25	1.8

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

Research is going on, to improve the quality of biopotential acquisition systems. As biopotential signals are in range of micro volts and milli volts, many remarkable circuits were developed till date for the amplification purpose, but in recent trends demand for implantable and wearable devices increased to a great extent. For implantable and wearable device applications low power circuits are generally preferred for the safety of patients. Most of the proposed circuits were consuming high power, so to overcome that problem an attempt is done to design bioamplifier with ultra low power consumption. Bioamplifier is designed in 180 nm CMOS process with a supply voltage of 1.8 V, in which transistors are operating in weak inversion region consuming power of 6.25 uW and amplifying signals in the frequency range of 5.02 Hz to 2.927 KHz with a midband gain of 45.38 dB. Results shows that proposed architecture with Wilson current mirror gives better performance in comparison with simple current mirror and cascode current mirror circuits. Designed bioamplifier can be used in the applications like BCI, biopotential acquisition systems, mind gaming industries etc.

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