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A Low Noise OPAMP with Chopper Stabilization for Biomedical Applications

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Abstract- **Operational Amplifier plays a key role in Analog circuits of which is the key area in biomedical application. In the field of Bio Medicine the bio potential signals are one of the basic signals that are monitored. A CMOS (Complementary Metal oxide Semiconductor) design comprising fully differential Operational Amplifier circuit decreases the noise present in the measured input bio potential signals. Bio potential signals are low frequency, low amplitude range signals. Hence the noise present in the Operational Amplifier is mostly flicker noise. At lower frequencies flicker noise dominates other component frequencies, therefore flicker frequency filtering forms the crux in noise removal. The fully differential Operational Amplifier is drawn from single differential Operational Amplifier to get low noise levels. The innovation of our design lies in the modified architecture of Operational Amplifier. The circuit with fully differential Operational Amplifier helps in scaling down of noise to 0.3nv/√Hz with a corner frequency of 10 Hz and 1v of power supply which performs better than the Fully Differential Operational Amplifier [1]. The Modified design in this paper has been implemented in Cadence 90nm technology.**

IndexTerms **- flicker noise, Chopper, corner frequency**

I. INTRODUCTION

Noise is a key design parameter in the design of any amplifier circuit along with Power, Area and other essential parameters. It resembles the behavior of the signal and gets amplified along with the original signal. When the input is amplified with noise it becomes increasingly difficult to differentiate the output from the amplified noise component at lower frequency of operation. Generally noise is calculated by the average power spectrum signal of the device standard noise. Power spectrum of CMOS Operational Amplifier is as shown in Fig.1 [2].In the Figure where 1/f noise converges, the thermal noise is termed as 1/f, and the corner frequency f_{knee}. In higher frequencies noise is independent of frequency and this is termed as thermal noise floor, below the corner frequency is the flicker noise. The Flicker noise power is inversely proportional to the input signal frequency. Noise is the random phenomenon present in the analog circuitry which affects the throughput of the device. Out of all the different noise components present two of them two are more predominating than the rest like Thermal Noise, Flicker noise (1/f noise) [3].Thermal noise occurs due to the random movement of electrons in a semiconductor device. Noise in the resistor is indicated by equation 1.where K is Boltzmann's constant, R is resistor is absolute temperature, and Δf is the bandwidth calculated where the noise is to be measured.

$$Vt = \sqrt{4KTR\Delta f} \quad (1)$$

Flicker noise occurs due to breakage of dangling bonds formed at the interfaces of gate oxide and silicon substrate at lower frequencies. Flicker noise is calculated like thermal noise and for this we require modeling of the MOSFET (Metal Oxide Semiconductor Field Effect Transistor) devices by

$$\overline{V_n^2} = \frac{k}{c_{ox}wL} \cdot \frac{1}{f} \quad (2)$$

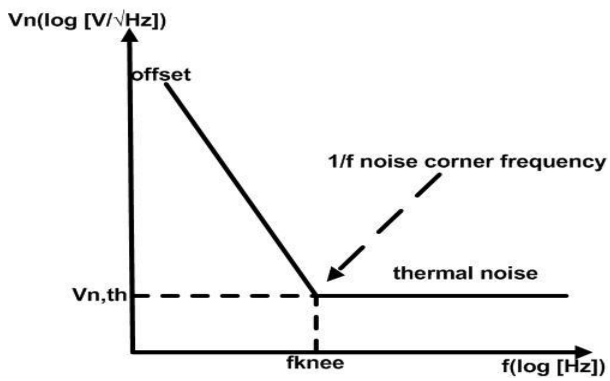


Fig. 1. Noise Of standard CMOS operational Amplifier

When input is of low frequency, lower bandwidth and low Amplitude signals such as Biopotential signals these signals create trouble. In this Biopotential signals like Electroencephalogram (EEG), Electrocardiogram (ECG) and Electromyogram (EMG) etc which are systems represented to calculate the signals of human/non human related to brain, heart and nerves etc, of which are listed in the table I [4].

Table I. Properties of several Biopotential signals

Devices	Measurement Range(Volts)	Gain(db)	Frequency range(Hz)
EEG	25-300µ	50-72	DC-150
ERG	5-900 µ	41-86	DC-50
EGG	10-1000 µ	40-80	DC-1
ECG	0.5-4m	28-46	0.01-250
EMG	0.1-5m	27-60	DC-500

Human /nonhuman signals are different in characteristic and vary in ranges of micro to milli volts. For identify the original signals from the duplicate signals there are different techniques [5] that are employed namely Autozeoring (AZ), correlated double sampling (CDS) and chopper stabilization (CHS) each and every one of them have their own advantages and disadvantages among them the chopper stabilized technique is most suitable one. First two techniques indicated are of sampling type while the last technique employs modulation. Modulation transposes low frequency signals of noisy signals to the higher frequency, the demodulator at end will demodulate the signal along with the low pass filter we can recover the original signal from the noisy signal present at very low frequency .The following sections are classified accordingly as in section II will explain the difference from present architecture and the modified architecture, section III shows the Implementation and Results. Section IV, V will be conclusion and future work.

II. ARCHITECTURE

In Fig.2, the total architecture of our noise limiting Amplifier which consists of an Operational amplifier,OP-AMP is the main heart in amplifying the signal from the chopper Amplifier, and the output of the Opamp is directed towards another chopper circuit which is acts as a demodulator that demodulates the signal. The other block is the integrator functioning as a low pass filter for noise removal at high frequencies, thus effectively shielding the rest of the circuit from the noise, As we are making the noise to shift to higher frequencies by chopping by passing through low pass filter we are removing the high frequency and noise components.

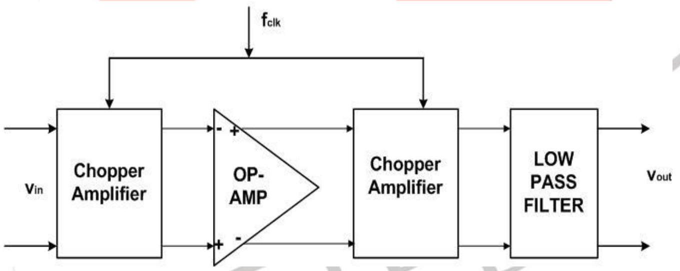


Fig.2. Block diagram

Flicker noise is the specific noise present in the CMOS technology and is exhibited at low frequency due to the imperfection in the silicon substrate and gate oxide in the technology manufacturing. This type of noise is reduced by the Chopper stabilized technique than the other sampling techniques. Flicker noise is less in PMOS(P-Channel) transistor than the NMOS(N-channel) transistor due to the mobility of electrons is more than mobility of holes by order of 2-3.in our design of OPAMP we used PMOS as the input to signal at both stages. We designed a fully differential Opamp with high gain, high swing voltage and which can handle good CMMR.

A. Operational Amplifier Design

The operational amplifier design is key to the entire Analog design circuit as it is the key for building the amplifier and integrator hence selection of the operational amplifier has to be done quite carefully the key parameters for its design include high gain for smoother integration and a large bandwidth for effective transmission of the signal, the remaining parameters of op-amp that are essential are high input impedance, gain margin and low output impedance. A two stage CMOS op-amp design has been implemented in this paper with a fully differential pair and a current source placed above the single stage. It is essential that appropriate sizing of the transistors must be done as it impacts the performance of the operational amplifier not only impacting its operating region but also the gain and the drain current values. As it is employed in the integrator design it is expected to have high gain for smoother integration with large bandwidth to pass better number of harmonics. Comparing both of the architectures with respective of present architecture and modified architecture shown in Fig 3 & 4, by the two stage Opamp single stage[6] is directed towards input to the PMOS device of second stage it contains miller capacitances for the single stage to second stage and also we add nulling resistor which improves the stability of OPAMP when it is operated in closed loop, nulling resistor value is chosen according to the inversely proportional to the transconductance ($1/g_{mp}$) [7]of the second stage PMOS transistor. Fully differential OPAMP has an advantage of having less voltage drop, less immunity to interface and also having less stray interface.

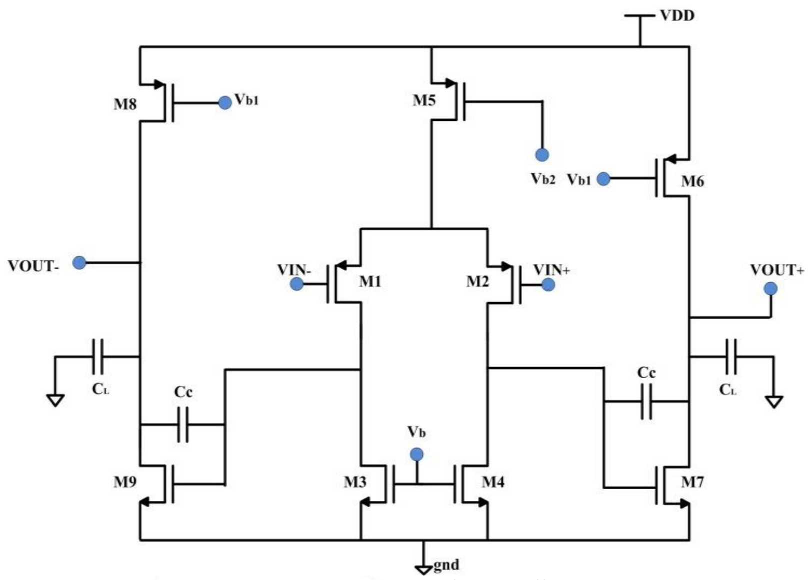


Fig.3. Previous Architecture of Fully Diff Opamp

B. Chopper Circuit

Chopper circuit will acts as both modulator and demodulator in our block diagram. Chopper stabilized technique fundamentally uses a pulse (carrier) to perform amplitude modulation on the input signal. Chopping technique requires pulse with period $T=1/f_{chop}$ where f_{chop} is the chopping frequency. In order to perform the analysis without any aliasing signal it is band limited to half of the chopper frequency [8]. Generally Amplitude modulation uses carrier transposing the signal higher frequency, where flicker noise is less in those frequencies and in the end we have a demodulator which will have the original signal. Mostly the signal is directed to the input of integrator where greater than half chopping frequency will be removed so mostly our signal is present in low frequency only.

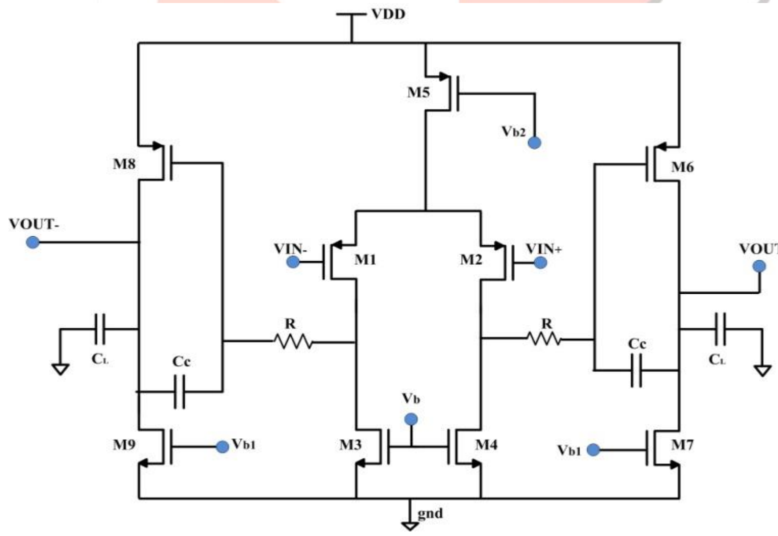


Fig.4. Modified Architecture of Fully Diff OPAMP

III. Implementation & Results

Implementation of architecture is done by combining each and every component from two stages Opamp, chopper circuit and low pass filter. Opamp which we have designed for our method was done by mingling of modified architecture circuit. In the operation of transistor in saturation region which makes MOSFET to amplify the input signal we have considered the simply common source amplifier and replicating of them helps in building the two stage fully differential Opamp circuit which is shown in above Figure in this first stage we are having M_1-M_5 where M_5 is the current source present over the tail current source which will be provide the current from drain current is equally divided among the two replicate half circuits in the next stage we are having the PMOS transistor as common source in the second stage.

Opamp to be operated in the closed loop we require stability of two stage Opamp. for this we are considering the nulling resistance with miller capacitance which will be providing necessary gain and the Phase Margin for the Opamp which is obtained as more than 60 degrees and gain of 57db with unity gain bandwidth of 200Mhz, and f_{3db} of 247.502KHz.which is shown in Fig 5.and the load capacitance of the Opamp must be high in order to drive the next device connected to it so we have load capacitance of 1pf.

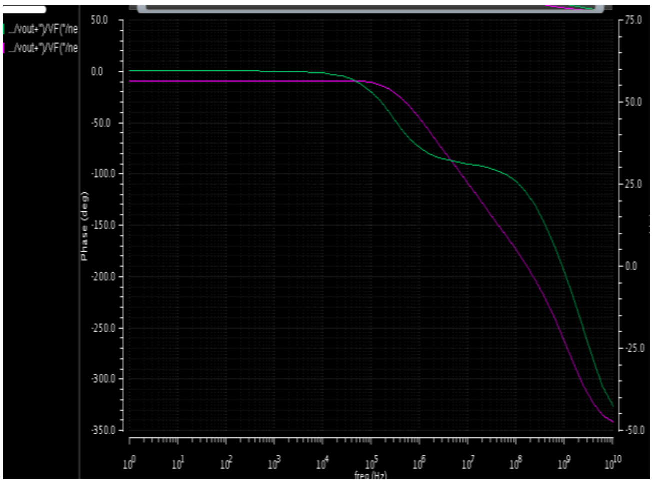


Fig.5. Ac gain of Opamp

When the signal is passed from the input to chopper modulator having two non overlapping phases of clock having 1 KHz of pulse signal if the pulse having low input then inversion is possible. When signal is high then no inversion takes place in this switch are indicated in Fig 6 where transistors operated in linear region, cutoff region to be operated as switch. Input to the chopper modulator is low frequency and low amplitude signals, noise of the Opamp circuit is shown in Fig 7 and in Fig 8 shows log scale of the input referred noise of Opamp.

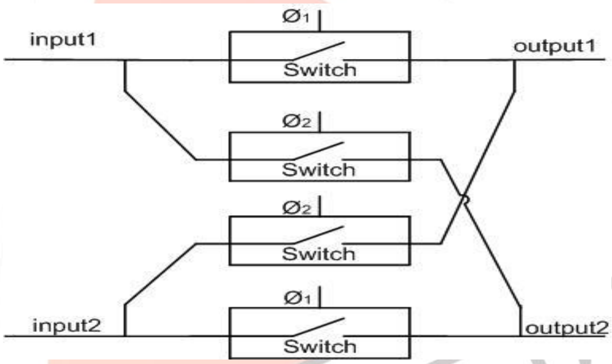


Fig.6. Chopper circuit

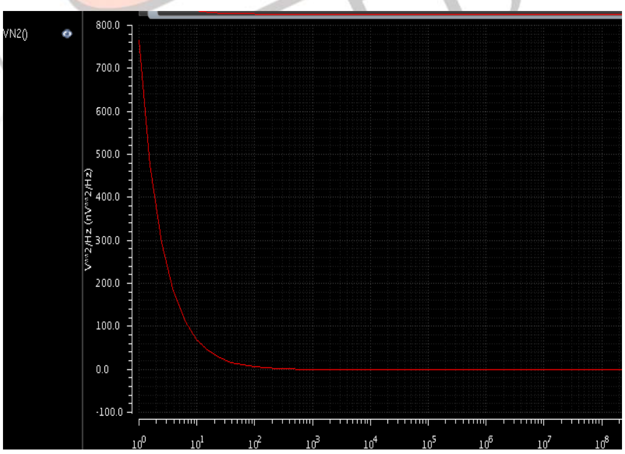


Fig.7. Noise of the Opamp

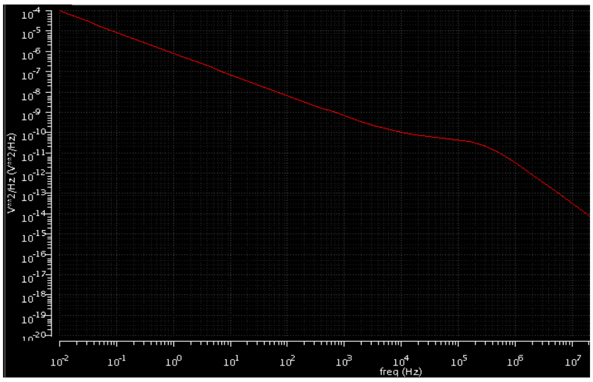


Fig.8. log scale noise in Opamp without chopping.

The inversion of signal by chopper takes place when $Ø_1$ is off and $Ø_2$ is on, MOSFET to be operated exact opposite of BJT transistor, when original signal is carried by noise. Chopper modulator circuit transposes the noise to the high frequency and Opamp will amplify the signal chopper demodulator demodulates Opamp output and the low pass filter shown in Fig 9 removes the noise from the signal where we having only the original signal we required.

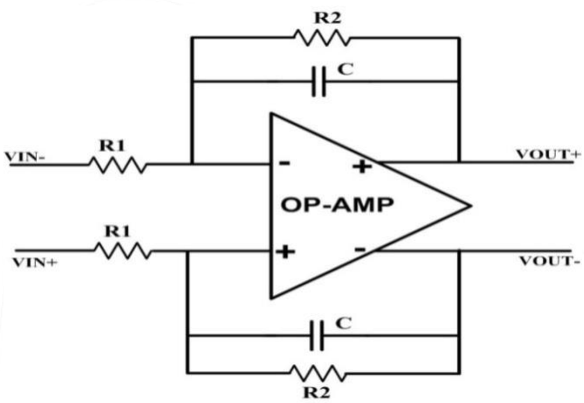


Fig.9. low pass filter

In Fig 10 shows the output waveforms of the chopper amplifier where we having input of the chopper and the chopper output in second row and final output in third row which is amplified by 100 times due to the gain present by operation of our Opamp.

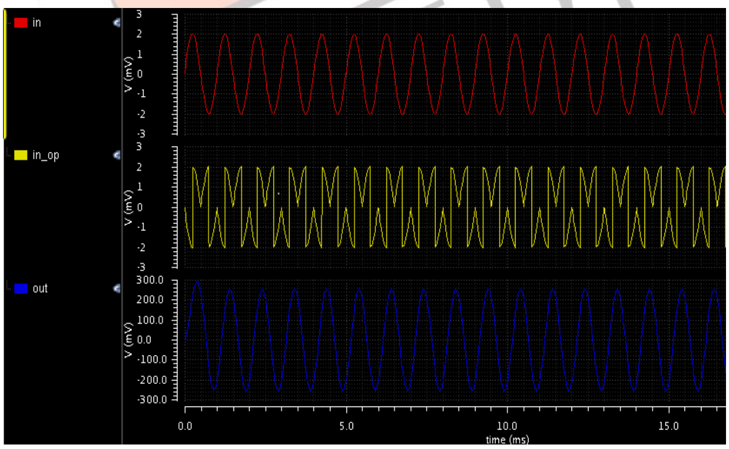
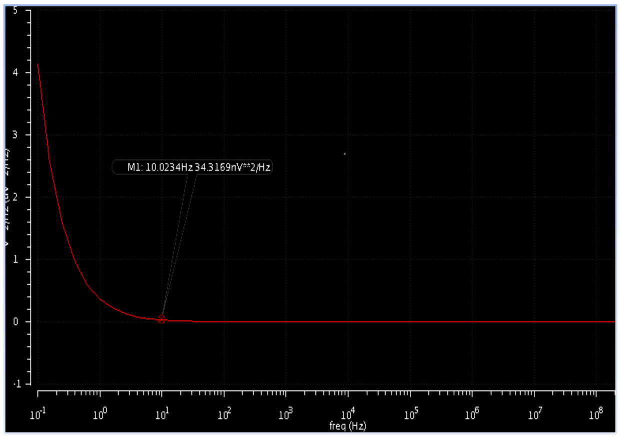


Fig.10. waveform of the circuit

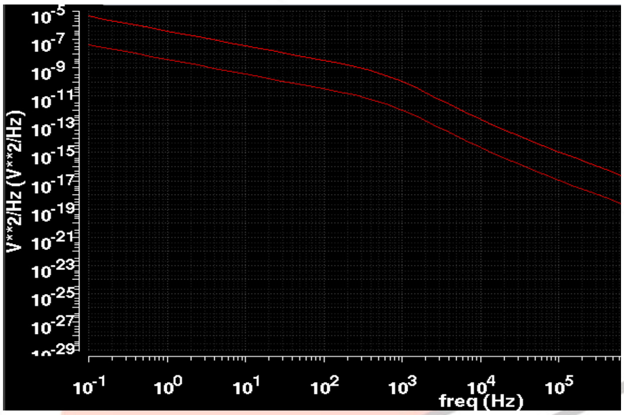
In closed loop with capacitively coupled capacitance present in feedback circuit with gain in equation 3

$$Gain = \frac{C_{in}}{C_{fb}} \quad (3)$$

Noise output of Chopper fully differential Opamp along with nv/√Hz with frequency along x axis is shown in Fig 11. Finally the difference between the noise of Opamp and same Opamp operated with chopper modulator and demodulator is shown in Fig 12 and table II shown the Implementation results which we have done so far. Above line indicates before chopping of Opamp referred noise and bottom line indicates after chopping referred noise.



(a)



(b)

Fig.11. Noise output (a) refers to the noise total by chopping. (b) Log scale of both output referred and input referred noise by G=100.

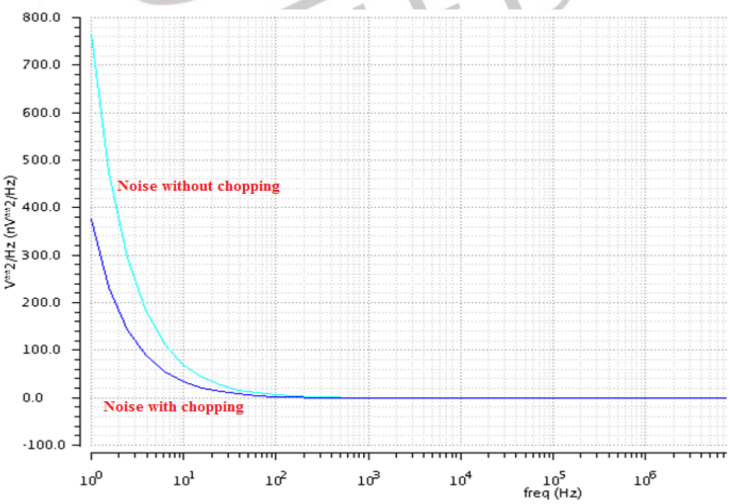


Fig.12. difference between Opamp and chopper referred noise

Table II. Implementation results

Technology	90nm
Voltage	1v
Input referred noise	38nv/√Hz
Phase margin	>60
Open Loop Op Amp Gain	57db
Slew rate	28 V/μs

IV. Future Work

Power is one of the trade-off for any design. Low power techniques for operational amplifier can also be considered and hence minimizing the power. Sub threshold region of operation to draw minimum current in order to minimize the power consumption will be considered rather than saturation region of operation.

V. Conclusions

A chopping modulation technique has been designed for signals of low frequency, amplitude signals. The two stage CMOS operational amplifier has been used to design both for amplifier and integrator circuit. The output is a continuous sinusoidal signal as the input signals which our Opamp having High CMRR greater than 90 db, and input referred noise of total circuit is 0.3nv/√Hz at 10Hz frequency. When signal is fed to a low pass filter, upon sufficient removal of the higher frequencies provided at the pre determined frequency provides the required original signal.

VI. Acknowledgment

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VII. References

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