IITB EE616 Mini Project Report Submission

PROJECT TITLE :

CHOPPER STABILIZED DIFFERENTIAL AMPLIFIER WITH RIPPLE SUPPRESSION TECHNIQUE

Submission Date:
02/12/2021

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ABSTRACT

Biosignals are low frequency and low voltage signals. Amplification of these biosignals signals is a very challenging task as the low frequency noise or the transistor flicker noise distorts these signals. Chopping technique is an effective way to mitigate the transistor flicker noise. The Chopper amplifier was discussed with different approaches to reduce the ripple, flicker noise and DC offset error. The single ended design implemented was then forwarded to double ended design. The input signals for which the circuits were implemented were of very low value (in terms of mV). The Chopper technique is very useful for removing DC offset error thereby improving the instrumentation amplifier and helps in small signal acquisition. But in chopper amplifiers, the residual offset is an issue mainly caused due to the demodulated clock feed-through spikes. To suppress the offset chopper ripple, the method of auto correction feedback (ACFB) is evaluated. The ACFB nulls out the amplifier's initial offset in the DC domain which would otherwise become modulated ripple at the chopper amplifier's output, instead of filtering the ripple with a post filter.

I. INTRODUCTION

Biomedical information such as electroencephalogram (EEG) and electrocardiogram (ECG) play a more and more important role in the diagnosis and treatment for various diseases. EEG/ECG signals have the characteristics of low amplitude and low frequency. The signal bandwidth is from 0.3 to 100Hz with signal amplitude less than 100 µV in the case of the EEG signal, and is from 0.1 to 150Hz with signal amplitudes less than 5mv for the ECG signal. So these signals need meticulous designing of the acquisition and recording units for capturing and storing these signals. Instrumentation Amplifiers can be used for signal acquisition with high CMRR but the DC offset error will be very high. In case of very low input signals the DC error will not give the correct output. So, to remove the DC offset error the Chopper stabilized method can be used. The Chopper Stabilized technique applies modulation to transpose the signal to a higher frequency where there is no l/f noise, and then demodulates it back to the baseband after amplification[1].

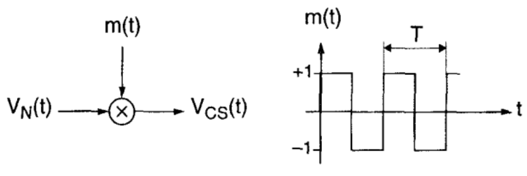

Fig 1. Chopper modulation

If input is limited to half of the chopping frequency then aliasing would not occur and the signal after modulation is transposed to odd harmonic frequencies. It is then amplified and demodulated back to the original band. The amplification would introduce DC error but the DC error would be modulated to higher frequencies after the signal demodulation. Thus, passing the signal through a LPF would remove the higher frequencies thereby removing the DC error and also the spiked (generated by switches because of their capacitive nature).

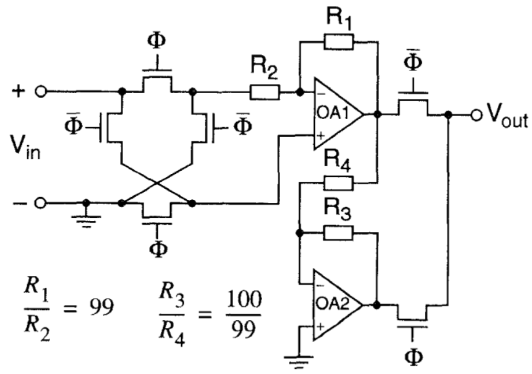

Fig 2. Single ended input chopper amplifier circuit

For the input signal $V_{in}(t)$ is passed through a chopper modulator $V_{ch}(t)$

$$V_{ch}(t) = \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) \tag{1}$$

The output of Chopper modulator is given by $V_{01}(t)$

$$V_{01}(t) = V_{in}(t) \, . \, V_{ch}(t) = V_{in}(t) \, . \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) \tag{2}$$

When the modulated signal is passed through an amplifier with gain of A which is adjusted by using resistors, an extra DC offset noise (V_N) is added. The output of the amplifier V_A is thus given as

$$V_A(t) = A.[\, V_{in}(t) \, . \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) + V_N \,] \tag{3}$$

Then the output of the amplifier $V_A(t)$ is then fed to another switching modulator.

$$V_d(t) = V_A(t).V_{ch}(t) = A.[\, V_{in}(t) \, . \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) + V_N \,] \, . \, [\, \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) \,]$$

$$V_d(t) = A.V_{in}(t) \sum_{n=1,3,5} \frac{2}{(n\pi)2} - A.V_{in}(t) \sum_{n=1,3,5} \frac{2}{(n\pi)2} \cos(2nw_{ch}t) + AV_N \sum_{n=1,3,5} \frac{2}{n\pi} \sin(nw_{ch}t) \tag{4}$$

The switching modulator output is then passed through a LPF to get the desired output

$$V_{out}(t) = A.V_{in}(t) \sum_{n=1,3,5} \frac{2}{(n\pi)2} = K.V_{in}(t) \tag{5}$$

Circuit with Differential Input and Output

In the single ended circuit seen previously the DC error in both half cycles will be different because in one half cycle when clock is high output will come from only one Op Amp and in the other half cycle the output will consist of DC errors from both the Op Amps. This problem can be solved using differential input and differential output amplifiers. The differential pair with the capacitive feedback is the most commonly used amplifier topology. chopping creates a ripple at the output of the amplifier, which is due to the up modulated amplifier offset and flicker noise. The design changes required for getting good performance is also to reduce the spikes generated because of the switching of input from +Vin to -Vin and the efficiency of the Low Pass Filter(LPF).

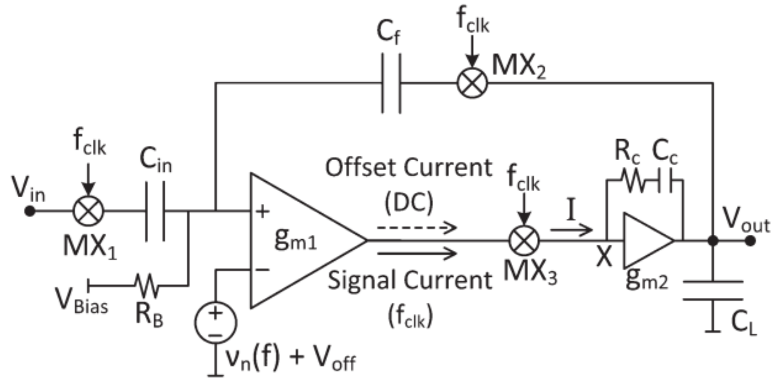

Fig 3. Conventional two stage chopper stabilized amplifier

Fig 3 shows the conventional two stage chopper stabilized amplifier [2]. In this circuit the gain g_{m1} is set low to keep the DC offset error as low as possible. To further mitigate the ripples a parallel RC is introduced between MX3(demodulator) and g_{m1} amplifier. It is shown in Fig 4 below.

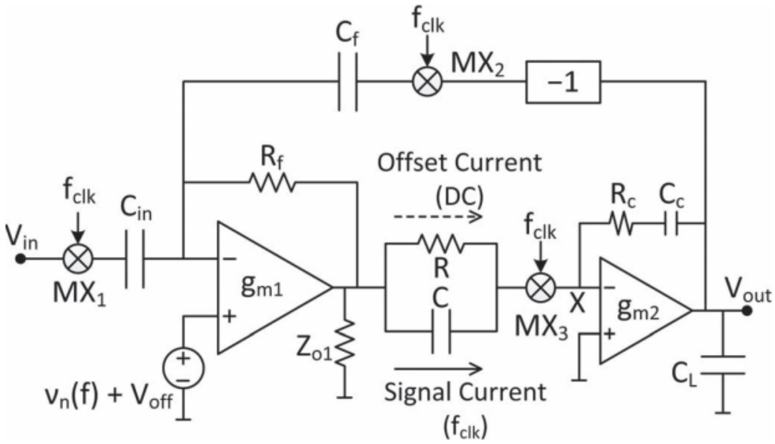

Fig 4. Two-stage chopped amplifier with ripple rejection

The primary cause of chopper ripple is the offset current generated by gm1. If the offset current is selectively blocked from flowing into the second amplifier stage, then the output ripple can be reduced. The parallel-RC impedance acts as an open circuit to gm1 at low frequencies if R is larger than Zo1 (the output impedance of gm1). At the chopper frequency, the parallel-RC impedance acts similar to a short circuit if the impedance of capacitor C (at fclk) is smaller than Zo1. To reduce the gain seen by the offset and flicker noise from gm1, a large resistor Rf is placed in feedback across gm1.

To increase the common mode range of the chopper amplifier the circuit shown in fig 6 can be implemented using alternate PMOS and NMOS in the 1st differential amplifier stage to give full rail to rail swing. This increases the input common mode range [3].

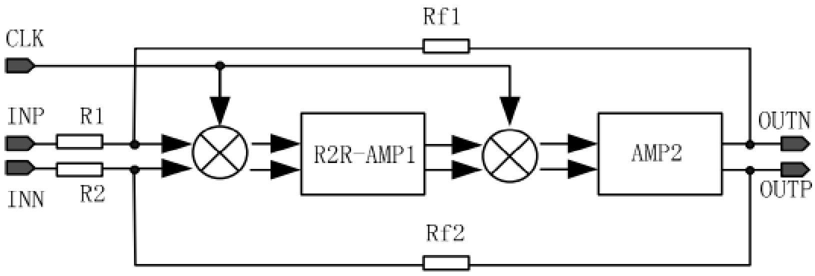

Fig 5. Chopper architecture[3]

Another approach to remove ripples is to null the initial offset of G_{m1} out before it is modulated by CHOP2, instead of filtering the modulated ripple out by a post filter as shown in Fig 6[4]. By the feedback operation, any DC offset current from G_{m1} is nulled out by G_{m4}, which would otherwise appear as ripple at the output of CHOP2 and at the output of G_{m2}. Because this method senses the modulated ripple at the input of G_{m2} instead of the output of the amplifier, the characteristics such as the loop gain of ACFB is independent of the output load or the closed-loop gain for the amplifier. It makes this method applicable to a stand alone operational amplifier[4].

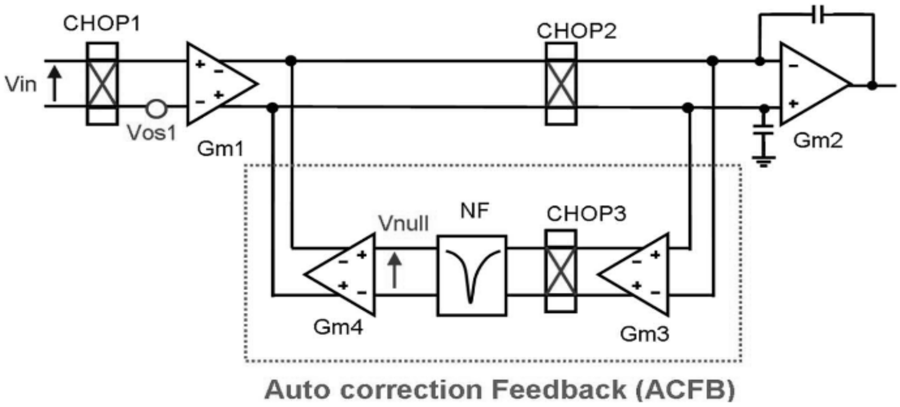

Fig 6. Ripple suppression method with auto correction feedback

II. CIRCUIT DIAGRAMS:

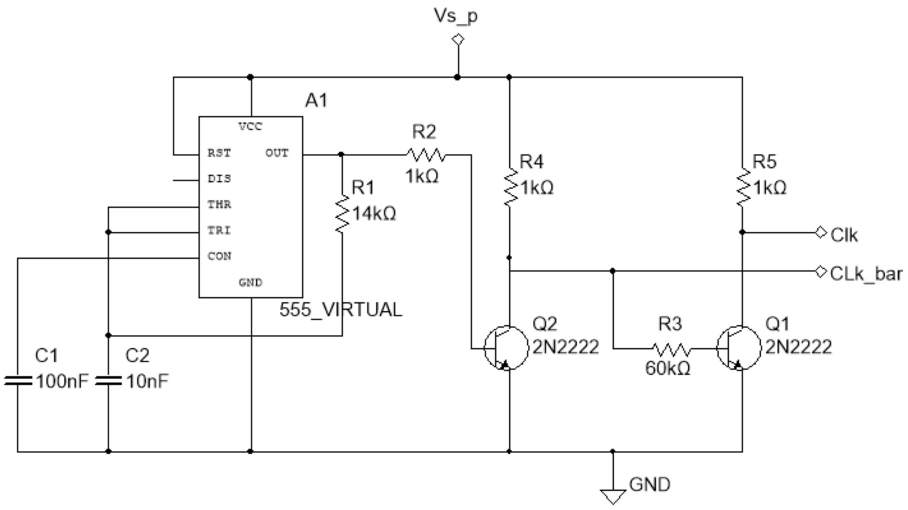

Fig 7. Switching Signals Generator Circuit

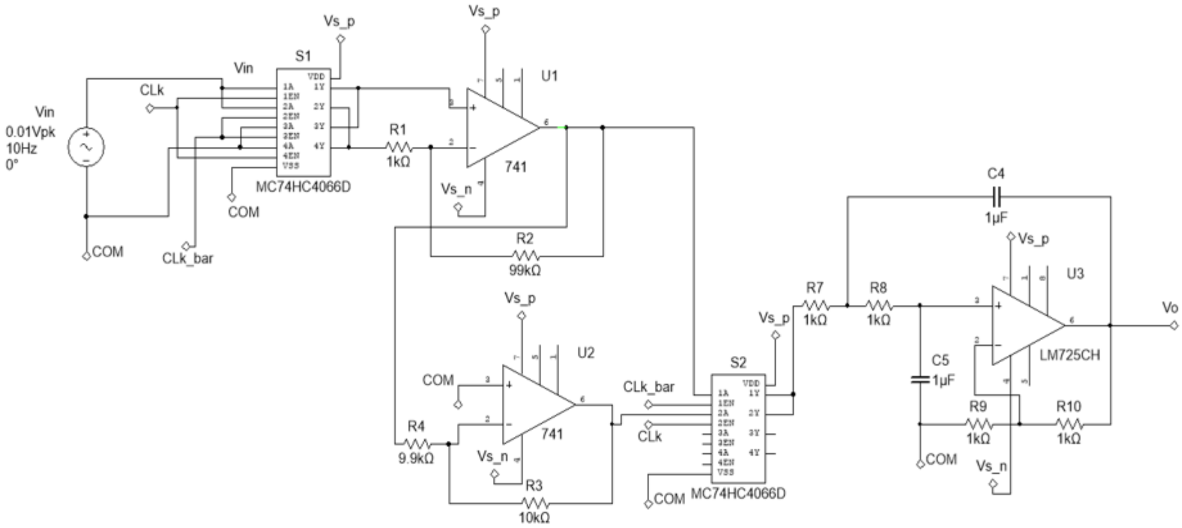

Fig 8.: Single ended chopper amplifier

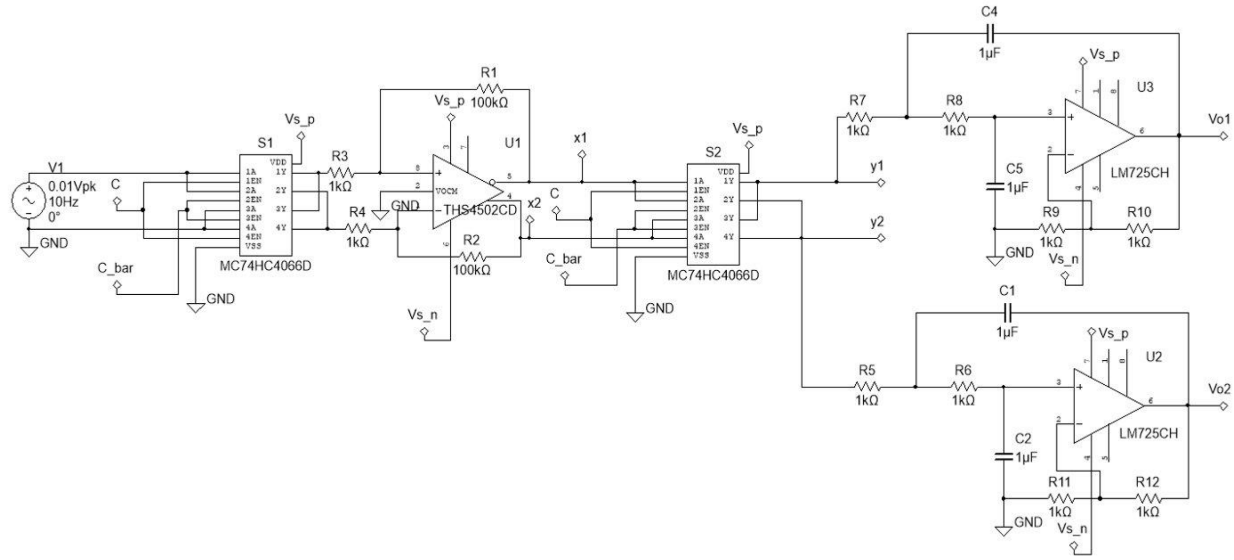

Fig 9. Differential ended chopper amplifier using operational amplifier

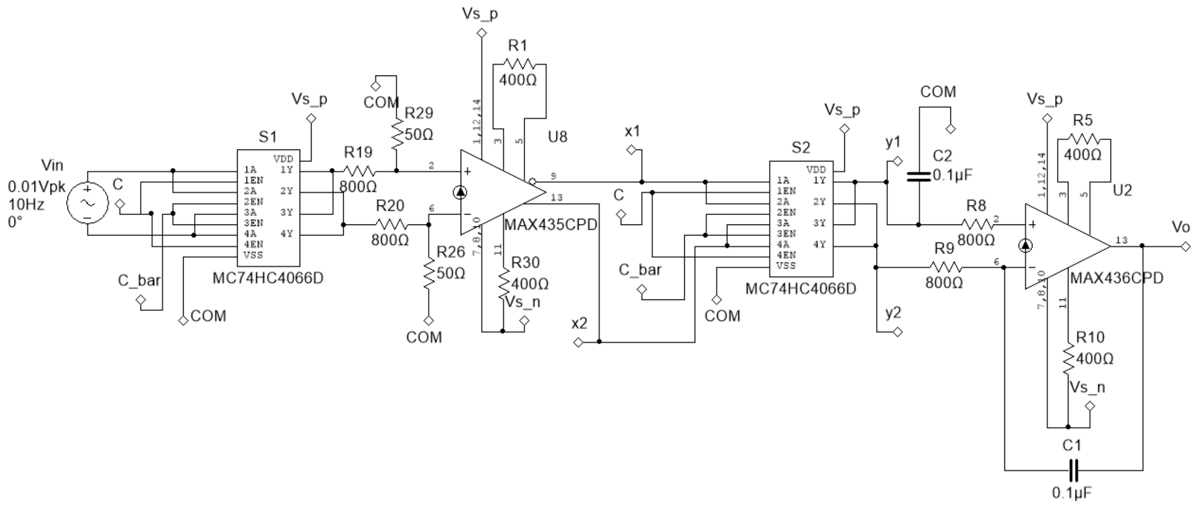

Fig 10. Differential ended chopper amplifier using transconductance amplifier

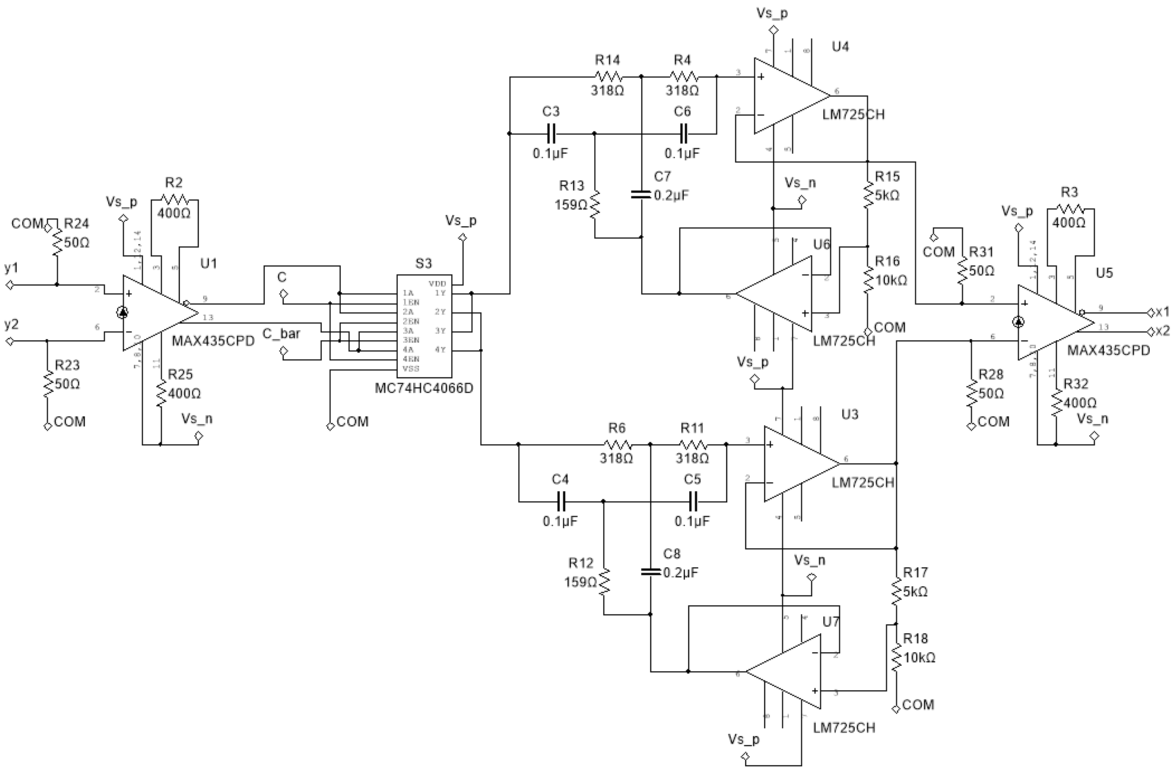

Fig 11. Auto-correction feedback circuit in addition to chopper stabilised amplifier using transconductance amplifier (ref. Fig 6)

III. EXPERIMENTAL RESULTS:

0.01V Sinusoidal signal of 10Hz is given at input to all configurations and A = 100.

Output waveform for single ended configuration:

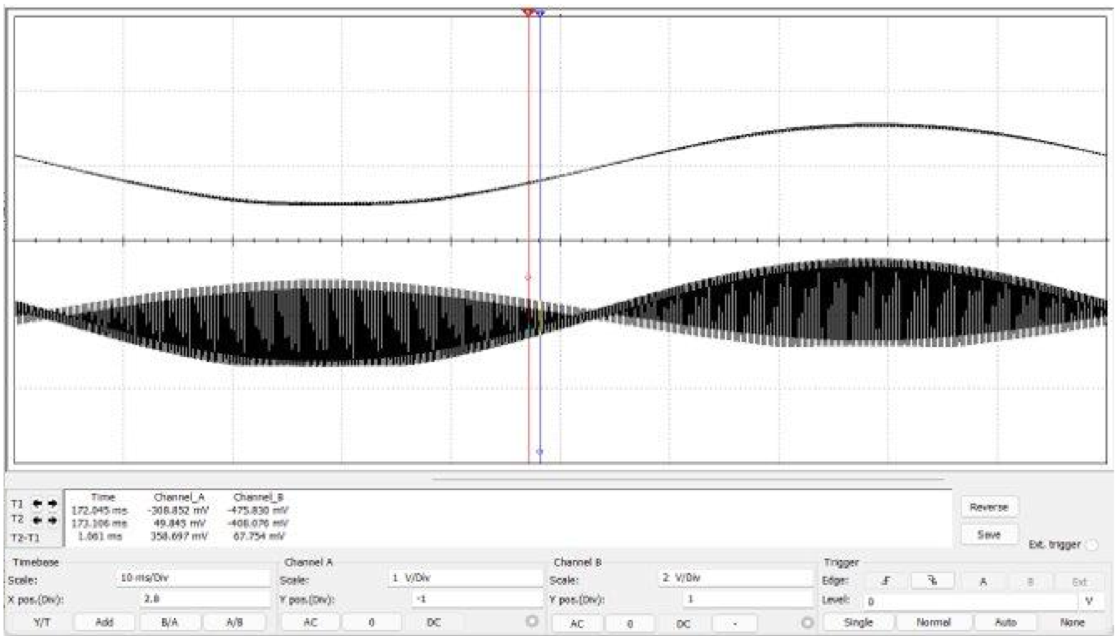

Fig 12. Demodulator output (above signal - channel A) and LPF output (below signal - channel B)

Output waveform for differential ended configuration using operational amplifier:

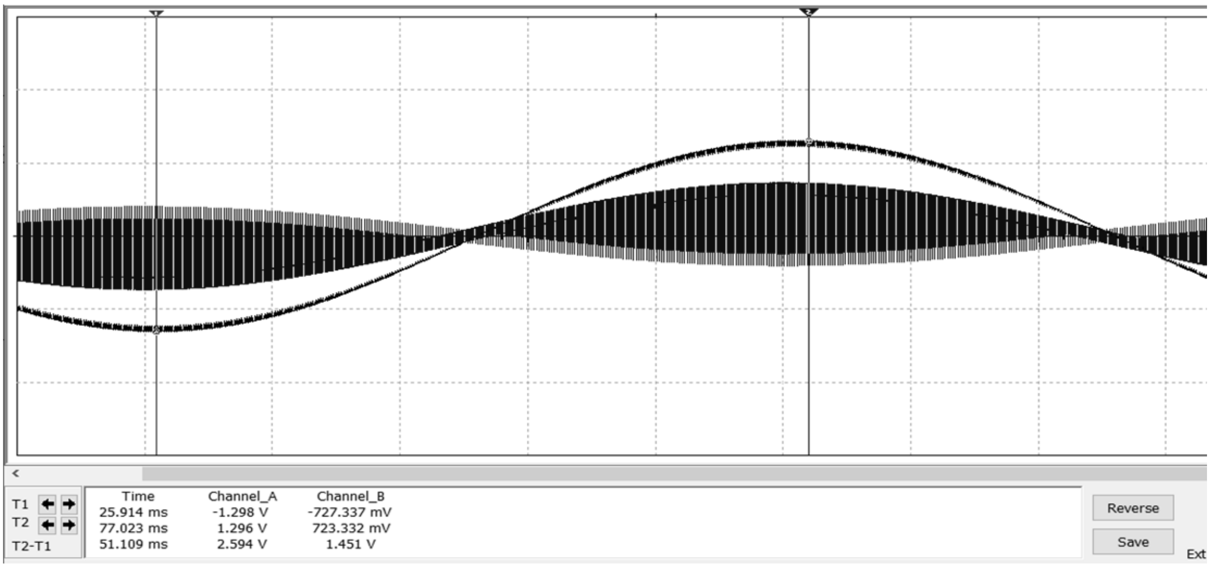

Fig 13. Demodulator output (above signal - channel A) and LPF output (below signal - channel B)

Output waveform for differential ended configuration using transconductance amplifier (R_L = 100):

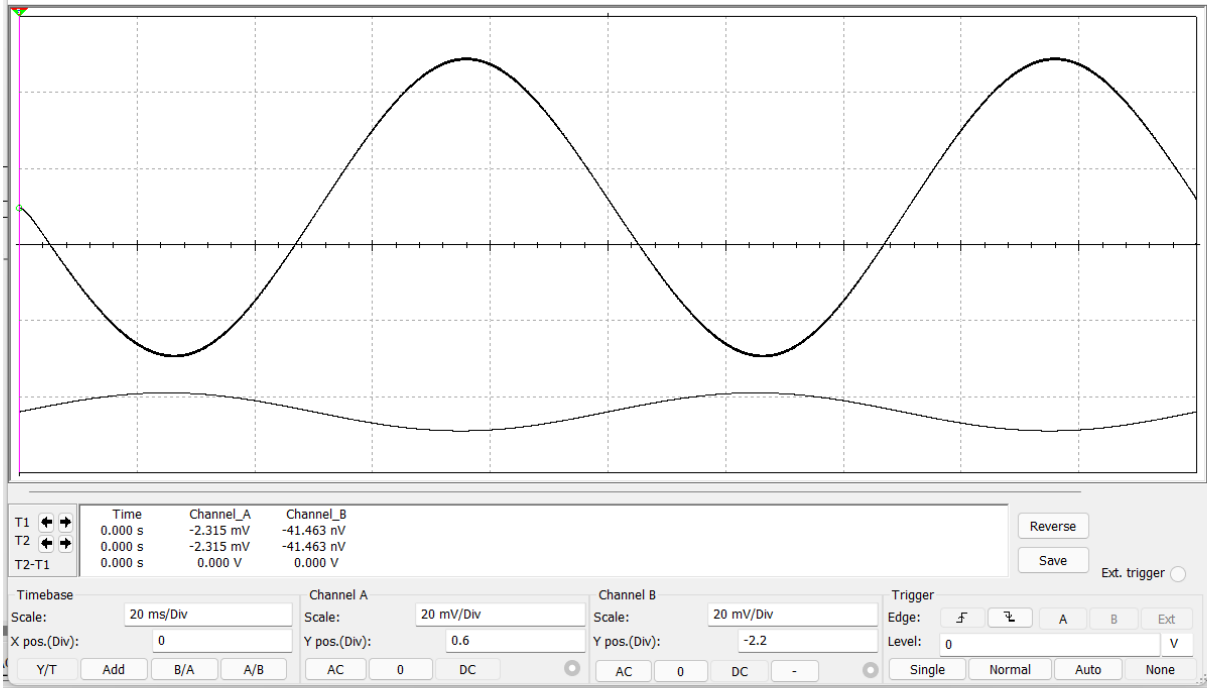

Fig 14. Demodulator output (above signal - channel A) and LPF output (below signal - channel B)

Output offset error using different schemes:

Sr.	Amplifier Configuration	Offset before LPF	Offset after LPF
1	Chopper stabilized single ended amplifier	57 mV	224 µV
2	Chopper stabilized differential amplifier	174 µV	2 µV

Table 1. Output dc offset error comparison

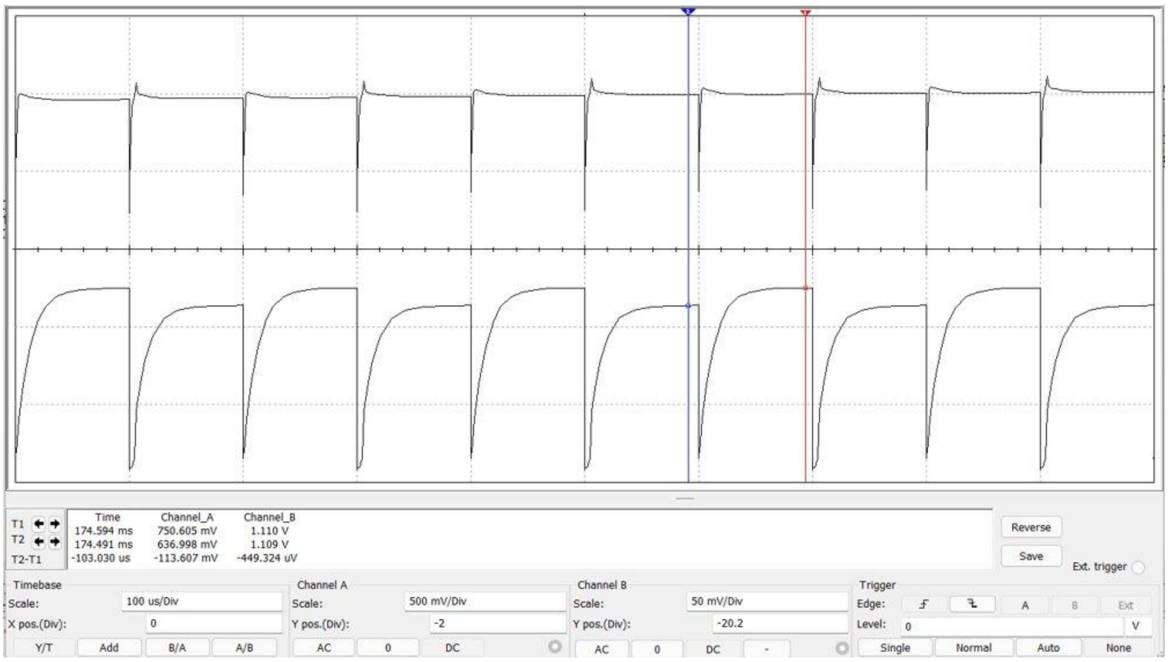

Fig 15. Output offset error for single ended amplification

Ripple comparison using different schemes:

0.01V Sinusoidal signal of 10Hz is given to all configurations and A = 100

Sr.	Amplifier Configuration	Ripple before LPF	Ripple after LPF
1	Chopper stabilized single ended amplifier	1.167 V	376 mV
2	Chopper stabilized differential amplifier	965 mV	25 mV

Table 2. Output ripple comparison

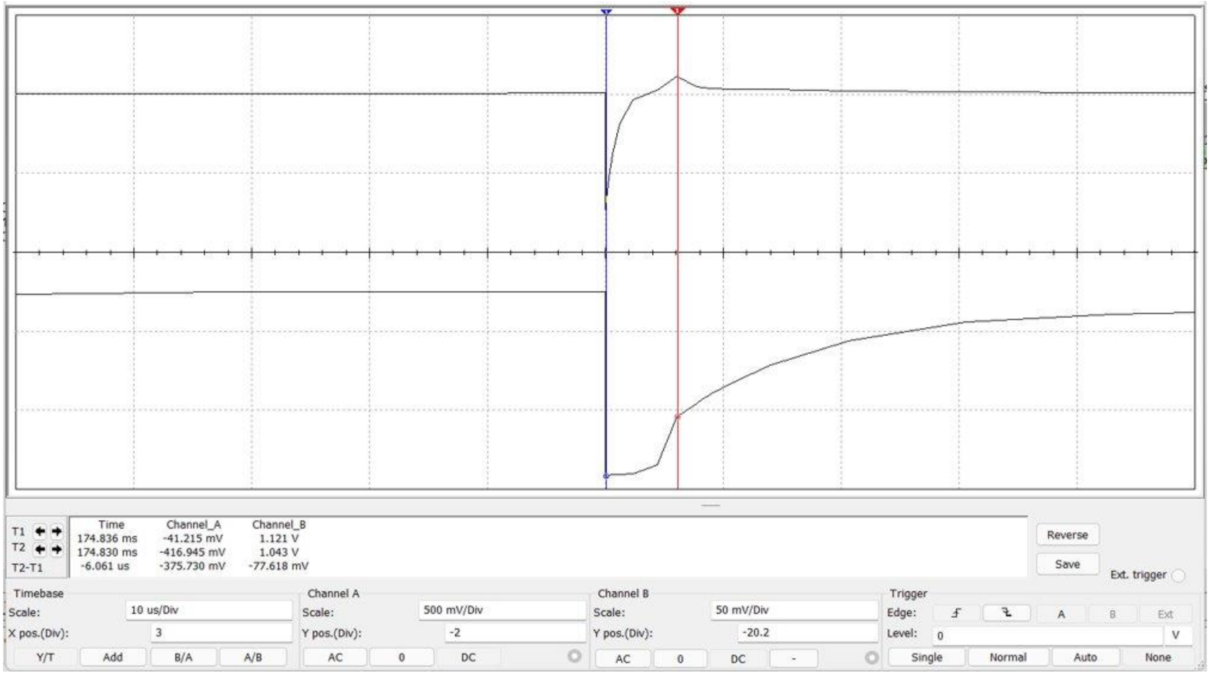

Fig 16. Ripple calculation for single ended amplification for the output after LPF (above graph - channel B)

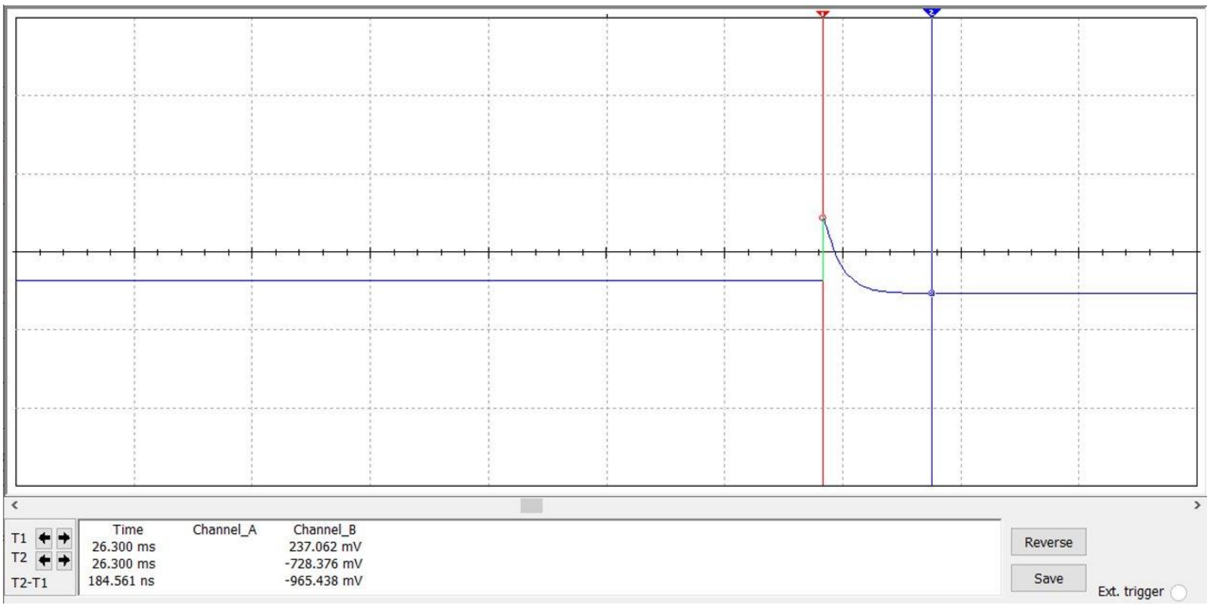

Fig 17. Ripple calculation for differential ended amplification for the chopper demodulator output

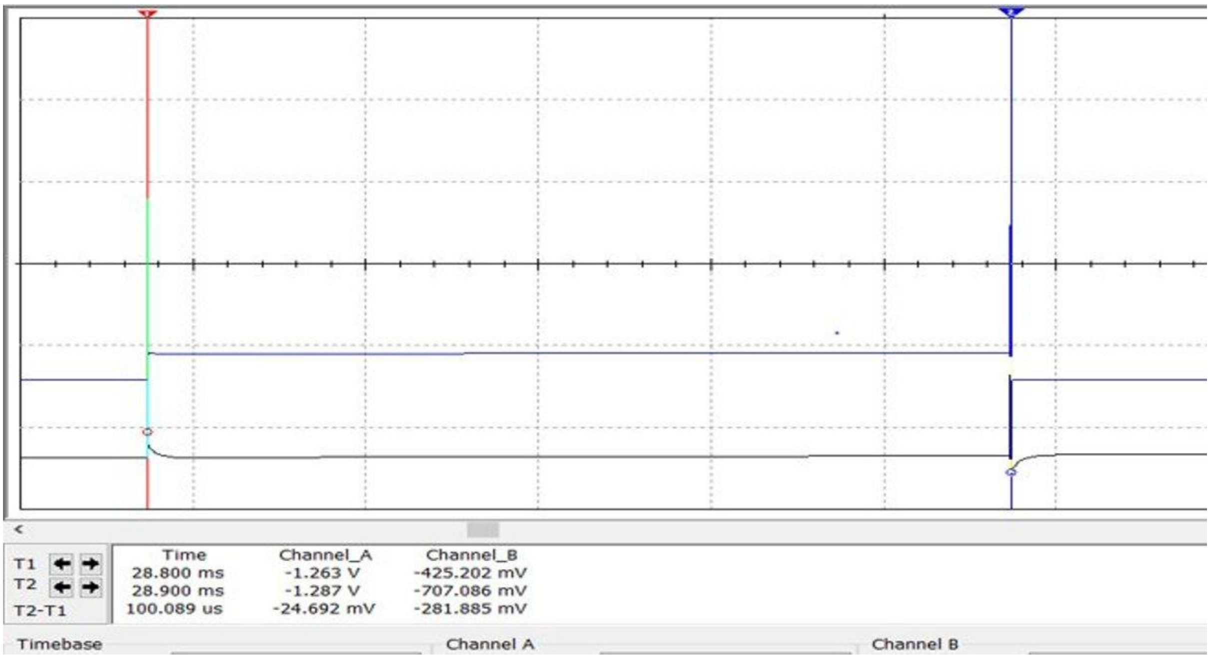

Fig 18. Ripple calculation for differential ended amplification for the output after LPF (below graph - channel A)

DISCUSSION:

Chopper stabilisation technique is selected to be analyzed for amplification of low voltage and low frequency signals. Circuit diagram from Fig. 2 is developed and simulated. The output waveforms are displayed in Fig. 12. Observation of residual offset and significant ripples at the output led to realisation of differential configuration.

Differential configuration significantly reduces the ripples due to the charge injection because of chopping action. The differential configuration is designed both using the operational amplifier in Fig. 9 and using the transconductance amplifier in Fig. 10. The output waveforms for both circuits using opamp and OTA circuits are displayed in Fig. 13 and Fig. 14 respectively. The ripples reduce significantly using differential configurations. Ripples produced in circuit using OTA are too less to be quantified (approximately in nV) in ideal conditions of the simulator.

Further devising a method to suppress practical level of ripples, a local feedback mechanism [4] is designed which targets to eliminate the initial offset of the main amplifier. It senses the output of the chopper demodulator and the sensed component is demodulated down to DC by another chopper using the same clock signals. The demodulated DC component passes through a Notch Filter and creates a null voltage at the output of Notch filter. It forms a feedback through the amplifier which is coupled to the output of the main amplifier. Hence, the feedback operation nulls out the ripple at the output of the chopper demodulator.

The designed schematic for Auto Correction Feedback (ACFB) is given in Fig. 11. We experienced simulation errors in transient convergence of the feedback circuit to be able to quantify results of the feedback mechanism.

IV. CONCLUSION:

The technique of chopper amplifiers for bio-signal amplification to achieve micro-level offset is reviewed. Analysis of single and differential ended chopper configuration is done and the auto-correction feedback method is discussed to suppress the chopper output ripple. The differential configuration is effective in compensating the charge injection. OTA configurations prove to be more immune against output ripples compared to opAmp configurations. Chopper stabilisation results in significant reduction in dc offset. More work on designing of ACFB technique is required to fully quantify the effectiveness of this method.

REFERENCE:

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[3] X. Yong, Z. Fei, S. Zheng and W. Yuanliang, "Design of novel chopper stabilized rail-to-rail operational amplifier," *2015 IEEE 11th International Conference on ASIC (ASICON)*, 2015, pp. 1-4, doi: 10.1109/ASICON.2015.7516988.

[4] Y. Kusuda, "Auto Correction Feedback for Ripple Suppression in a Chopper Amplifier," in *IEEE Journal of Solid-State Circuits*, vol. 45, no. 8, pp. 1436-1445, Aug. 2010, doi: 10.1109/JSSC.2010.2048142.