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ISOLATED ECG AMPLIFIER WITH RIGHT LEG DRIVE

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Abstract— This paper deals with development and testing of right leg drive (RL) circuit along with ECG amplifier with ground isolation circuit. Suitable band pass filter has also been incorporated for reducing the noise. Preliminary results showing the effective improvement in CMRR by incorporation of the RL drive are included in this paper.

Keywords— ECG signal, RL Drive, 50Hz Interference, Isolation, transformer, Instrumentation Amplifier, filter.

1. INTRODUCTION

Electro cardio graphic signal generally referred to as ECG signal, represents the electrical activity of Heart. Hence it serves as a useful diagnostic tool for cardiologist to assess, non invasively, the functioning of the human heart and detect abnormalities in the same. This signal is picked up from the upper thoracic region or upper arm of human body with the help of suitable electrodes. Generally the "Right Leg" is used as reference terminal. However the signal picked up by ECG leads is not clean. It is masked with noise components from skin electrode contacts, movement of the person, electrical noise in the preamplifier and other signal pickups. The worst contribution comes from coupling of main power line signal (50Hz A.C) from the electrical wiring and loads in the vicinity. All these unwanted components can severely degrade the ECG signal. Isolated ECG amplifier with provisions are made for reducing the mains pickup by providing a cancellation signal using RL Drive and ensuring patient's safety using isolation technique, the paper describes the circuits designed and some test results.

2. ECG Amplifier circuit:

The block diagram of the ECG amplifier is illustrated in the Fig 2.1.Itconsist of standard ECG electrode, instrumentation amplifier, modulation, transformer, demodulation, filter and amplifier. The focus of the work is enclosed within the box. The differential signal is acquired through two electrodes and third electrode is connected to right leg to further reduce common mode voltage. The operation of each block is explained below. Then, the differential ECG signal is sensed and amplified, modulated, coupled through an isolating transformer, demodulated and filtered and then amplified to a desired level. The RL drive is also incorporated to reduce common mode signal.

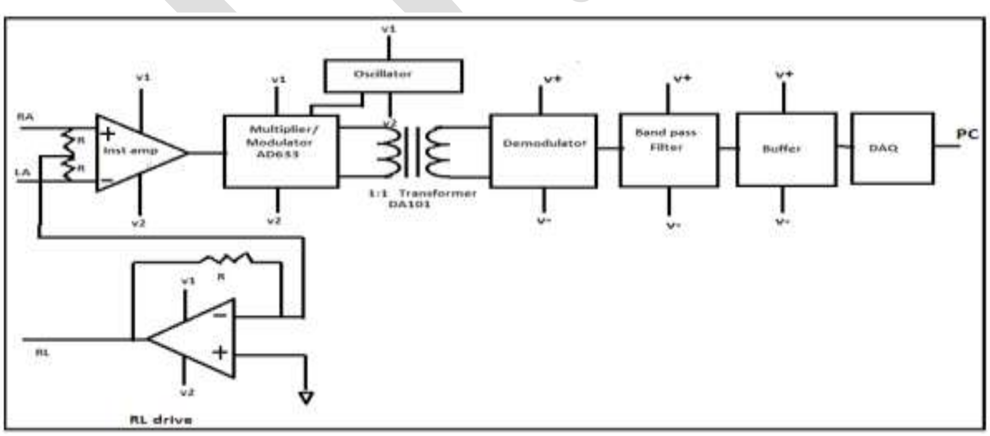

Fig 2.1: Isolation amplifier for ECG signal

2.1. Nature of ECG Signal:

An electrocardiogram (ECG) is a graphic recording of the changes occurring in the electrical potential between different sites on the skin (leads) as a result of cardiac activity. ECG wave represents a flow of electricity and it can be detected by electrodes placed on the surface of the body. One common placement of the electrodes is based on Einthoven's triangle, Fig 2.1.1 shows Einthoven's Triangle which is a theoretical triangle drawn around the area of the heart. Each apex of the triangle represents where the fluids around the heart connect electrically with the limbs. Separate amplifiers are placed at each of the three points of the triangle, and data from Leads I, II, and III is acquired. However, Einthoven's law states that if the values for any two points of the triangle are known, the third can be computed. Data will be collected from Leads I and II, with the difference of these two channels being equal to Lead III.

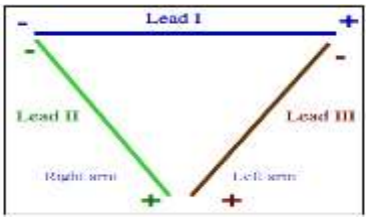

Fig 2.1.1: Einthoven's Triangle

The signal voltage can range from 0.5mV to 5mV and is susceptible to artifacts that may even be larger than it. The frequency components of human's ECG signal fall into the range of 0.05 to 100Hz and as far as the noise is concerned, contribution from the muscle movements, mains current and electromagnetic interference tend to degrade the signal. ECG waveform shown in Fig 2.1.2. It is a combination of P, T, U wave, and a QRS complex. The complete waveform is called an electrocardiogram with labels P, Q, R, S, and T indicating its features [8].

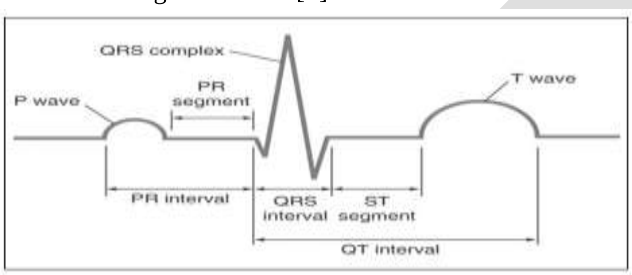

Fig 2.1.2: ECG waveform

Following is the list of events that occur in the heart on each heart beat.

1. Atrium begins to depolarize.
2. Atrium depolarizes.
3. Ventricles begin to depolarize at apex. Atrium re polarizes.
4. Ventricles depolarize.
5. Ventricles begin to re polarize at apex.
6. Ventricles re polarize

Fig 2.1.3 shows heart behavior and part of the generated signal.

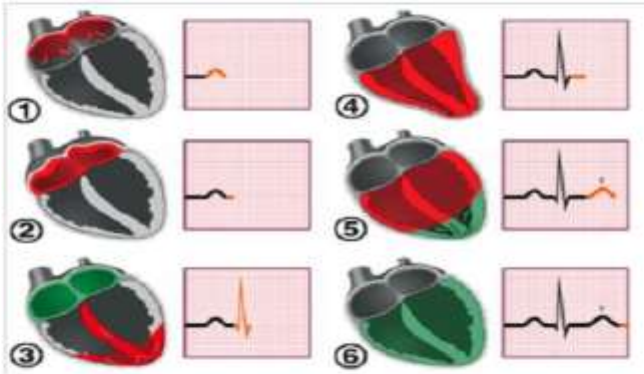

Fig 2.1.3: Electrical Activity of the Heart.

Fig 2.1.4 shows time approximate duration between events of ECG signal.

Feature	Duration
P wave	<80 ms
PR Interval	120 to 200 ms
QRS complex	80 to 100 ms
T wave	160ms

Fig 2.1.4: Time duration between different events of ECG signal

2.2. ECG pre Amplifier:

ECG is a low amplitude signal of 0.5mv to 5mv. Thus amplification is required in order to increase the signal amplitude for further processing and recording. Also, the ECG voltage V is not the only signal found at the input of the amplifier, it also contains noise generated by power line interference of 50Hz, muscle contractions, respiration, or other mechanism. ECG Signal is the difference in potential between a pair of electrodes. On the other hand, the 50Hz noise voltage is common to each electrode i.e.it appears equally at both the Right Arm and Left Arm. Rejection of 50Hz interference therefore depends on the use of a differential amplifier at the input stage, the amount of rejection depending on the ability of the amplifier to reject common mode signals. When more than 60dB of common mode rejection is required, generally three op amp amplifier circuit is used, which is known as instrumentation amplifier. Instrumentation amplifier offer high input resistance, adjustable differential gain, and high common mode rejection ratio (CMRR).

Fig 2.2.1 shows instrumentation amplifier designed using three op amp U1, U2 and U3. Op amp labeled as U1 and U2 act as buffers and U3 as differential amplifier. This circuit provides gain of 50. [4]

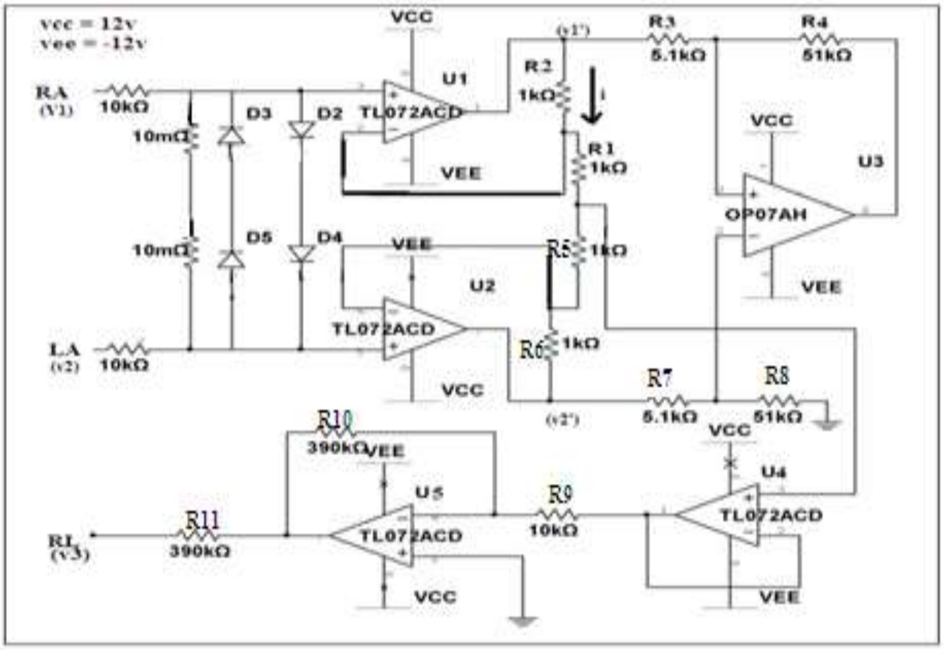

Fig 2.2.1: Instrumentation Amplifier with RL Drive Circuit

The differential signal RA and LA applied across v1 and v2 of Fig. 2.2.1 induces a current i, to flow through R1 and R2.Equation shows current equation.

$$\mathbf{i} = \frac{\mathbf{v1'-v1}}{\mathbf{R2}} = \frac{\mathbf{V1-V2}}{\mathbf{R1}} = \frac{\mathbf{V2-V2'}}{\mathbf{R2}} \qquad (\mathbf{1})$$

Equation 2 and 3 shows voltage at both the inputs of differential amplifier.

$$V1' = \left(1 + \frac{R2}{R1}\right) V1 - \frac{R2}{R1} V2 \qquad (\mathbf{2})$$

$$\mathbf{V2'} = \left(\mathbf{1} + \frac{\mathbf{R2}}{\mathbf{R1}}\right) \mathbf{V2} - \frac{\mathbf{R2}}{\mathbf{R1}} \mathbf{V1} \qquad (\mathbf{3})$$

The voltage gain of the instrumentation amplifier is be expressed by using the equation below.

$$\mathbf{V2' - V1'} = (\mathbf{V2 - V1}) \left(\mathbf{1} + \frac{\mathbf{2R2}}{\mathbf{R1}}\right) \qquad (\mathbf{4})$$

i.e. the first two op amps and associated resistors give a differential gain *Ad* of $\left(\mathbf{1} + \frac{\mathbf{2}\boldsymbol{R2}}{\boldsymbol{R1}}\right)$
Diodes are used to protect circuit from transient voltage signal which are generated by the movements of patient.
The overall common mode rejection ratio (CMRR) is approximated by following equation:

$$\text{CMRR} = \frac{Ad}{Acm} = \frac{Ad1.Ad2}{Acm1.Acm2}$$

where Ad id differential gain of U1 and Acm is common mode gain of U2.

2.3 RL drive circuit:

In order to further reduce common mode on human body, we have used RL drive technique where in the amplitude of common mode signal present in ECG signal is sufficiently effectively reduced at input itself with the help of high gain inverting op amp. U4 is a unity gain amplifier and U5 is the inverting amplifier. U4 picks up the common mode signal which has been sensed at junction of resistor

R1, U5 amplifies it and feeds it back to RL of patient, this reduces amplitude of common mode signal at input; there by enabling clearer signal at the output [11].

2.4 Amplitude Modulation:

Modulation of ECG signal is required for obtaining galvanic isolation which is provided by transformer. Wien bridge oscillator is designed to generate frequency of 50KHZ which will serves as career signal and ECG signal will act as message signal [5]. Amplitude modulation is achieved by using multiplier IC AD633 shown in fig 2.4.1.Pin discription is shown in the fig 2.4.2.AD633 is a, four quadrants, analog multiplier. Four quadrant means that both operands that are multiplied can take any polarity i.e. +/ -. It includes high impedance, differential X and Y inputs, and a high impedance summing input (Z).

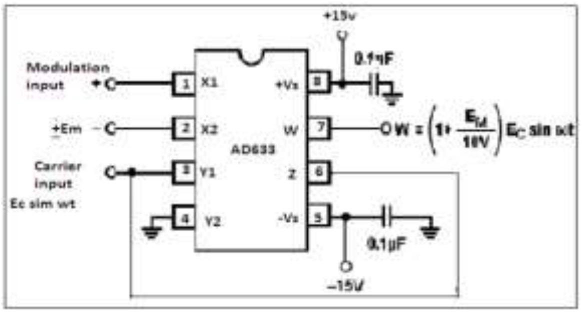

Fig 2.4.1: AD633 IC pin

Pin no.	Mnemonic	Description
1	X1	X multiplicand non inverting input
2	X2	X multiplicand inverting input
3	Y1	Y multiplicand non inverting input
4	Y2	multiplicand inverting input
5	-Vs	Negative supply rail
6	Z	Summing input
7	W	Product output
8	+Vs	Positive supply rail

Table 2.4.2: 8-Lead PDIP Pin Function Description

2.5 Oscillator

Amplitude modulation requires a high frequency (carrier) signal which is generated by oscillator. Fig 2.5.1 shows Oscillator Circuit. [6]

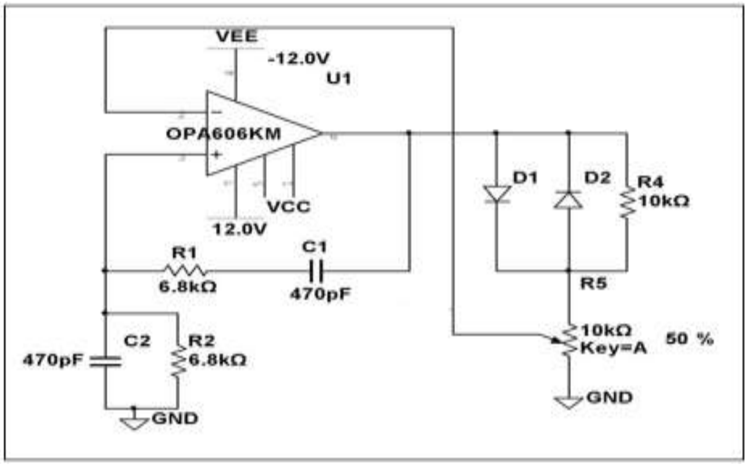

Fig 2.5.1: Wien Bridge Oscillator Circuit

To obtain sustain oscillations Barkhausen criteria should be satisfied. This means that

1. The magnitude of the loop gain must be nearly unity or slightly larger
2. Total phase shift, ϕ of the loop gain must be N x 360° where N=0, 1, 2, …

The condition of zero phase shift is achieved by balancing bride. Fig 2.5.2 shows bridge network.

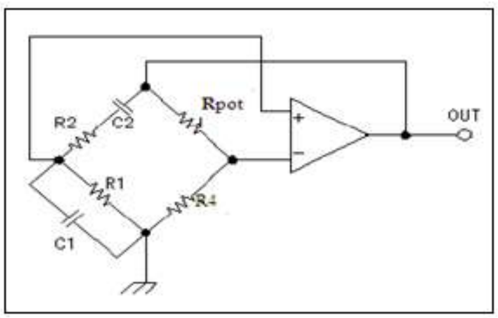

Fig 2.5.2: Bridge Network

The oscillation frequency can be calculated by the following formula.

$F0= \frac{1}{2\pi\sqrt{R1R2C1C2}}$

When R1=R2=R and C1=C2=C,

$F0 = \frac{1}{2\pi RC}$

2.5.1: 50 kHz oscillator

$F0= \frac{1}{2\pi\sqrt{R1R2C1C2}}$

R1=R2=6.8k

C1=C2=470pf

And R1=R2=R and C1=C2=C,

$F0 = \frac{1}{2\pi RC} = 49.7$ KHz

2.6 Transformer

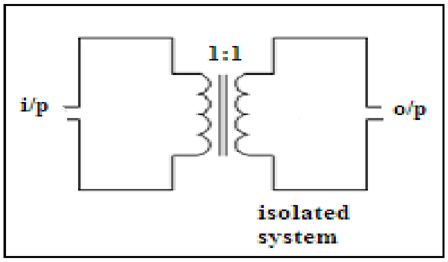

Fig 2.6.1: 1:1 Transformer

Transformer is used to provide galvanic isolation. Transformer used has primary: secondary turn ratio of 1:1 as shown in the Fig 2.6.1 [9] .With the use of this transformer, ground of the instrumentation amplifier, oscillator and modulator gets isolated from further circuit. To achieve ground isolation separate power supply is given before transformer. Fig 2.6.2 shows the power supply circuit .Due to the formation of ground loop is minimized and patient gets protected from hazardous ground loop.

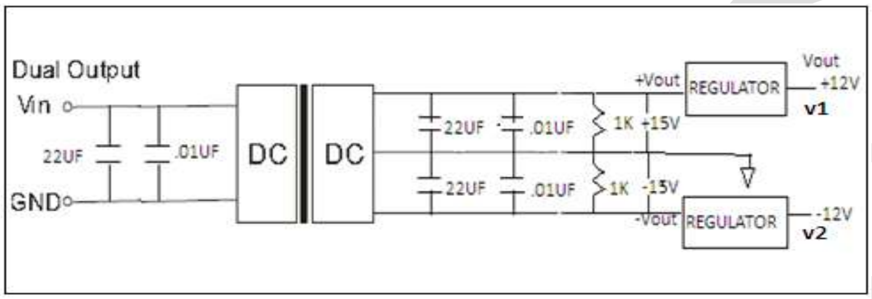

Figure 2.6.2: Power supply

Separate power supply is provided using PVB3-D5-D15-D which is DC to DC converter; the 5V DC input generates regulated 15V output. It is followed by 7812 and 7912 series regulators which are used to provide a stable DC voltage of 12V for powering circuit. Fig 2.6.3 shows isolated ground section of the ECG amplifier.

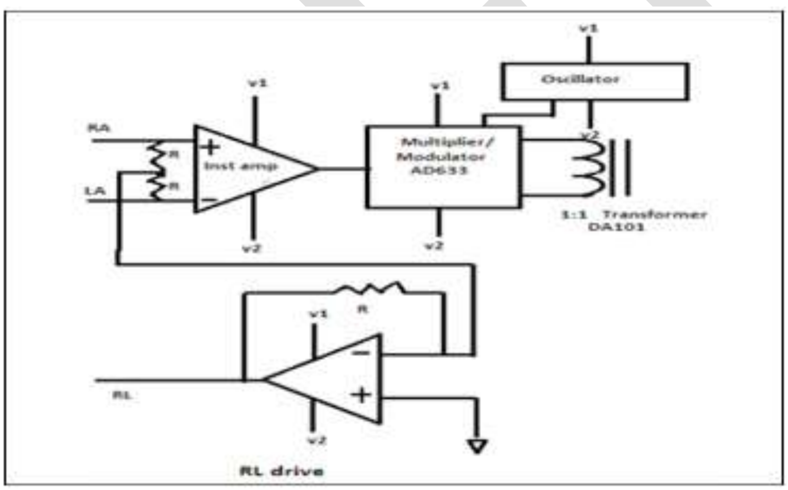

Fig 2.6.3: Isolated Ground section of ECG amplifier

2.7 Demodulation/Detection

The outputs of secondary section of the transformer consist of modulated ECG signal. For further use, thus signal must be Demodulated and envelop detected so that only the ECG signal is available for further processing. Diode D1 serves as an AM detector and the RC network forms a low pass filter that removes the carrier signal [10].Fig 2.7.1 shows demodulation circuit.

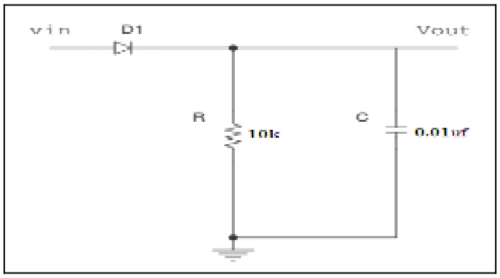

Fig 2.7.1: Diode based AM demodulator and envelop detection circuit

2.8 Band Pass Filter

Subsequent to pre amplification it is necessary to filter the signal, so that the noise contributed by muscle contractions, respiration, or other mechanism is attenuated for obtaining cleaner ECG signal. The bandwidth of the bandpass filter matches that of ECG signal. Thus out of band noise is rejected by this filter[12]. Fig 2.8.1.1 filter is a combination of high pass butterworth filter and low pass butterworth filter.

2.8.1 Band-Pass Filter (0.5 Hz–100 Hz)

The values for capacitors and resistors and the respective process to obtain the cutoff frequencies are described below:

Lower Cutoff Frequency (0.5 Hz): C =475 nf , R =680 KΩ

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi*680*10^3*475*10^-9} = 0.49\text{Hz}$$

Upper Cutoff Frequency (100): C=1uf, R=1.5 KΩ

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi*1.5*10^3*1*10^-6} = 106\text{Hz}$$

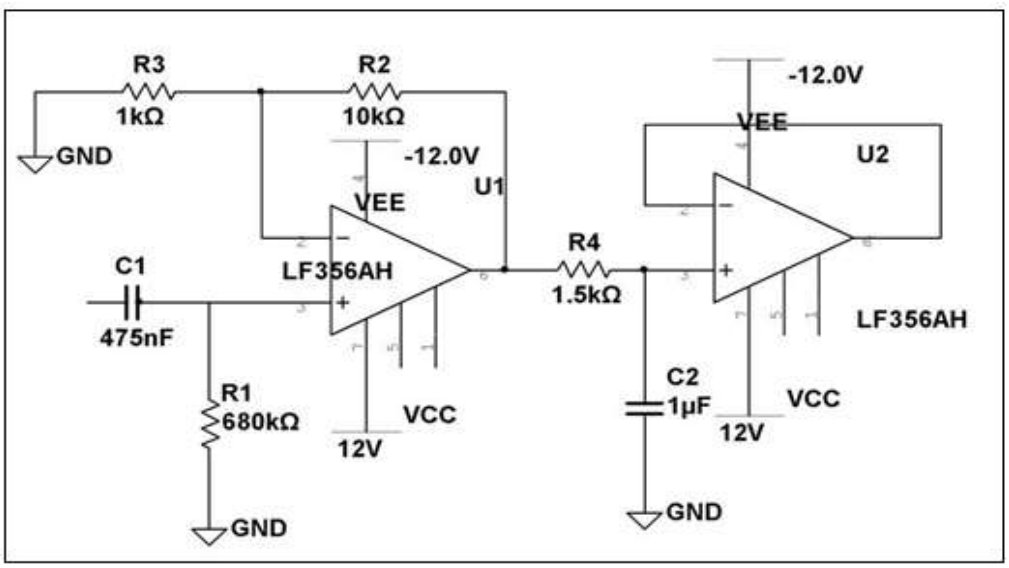

Fig 2.8.1.1: Band Pass Filter

3.RESULTS

Fig 3.1 shows a trace of the ECG signal obtained without the provision of RL drive (RL electrode connected to ground). Fig 3.2 shows a trace of the ECG signal obtained with RL drive connected .The waveform can be seen to be much clearer.

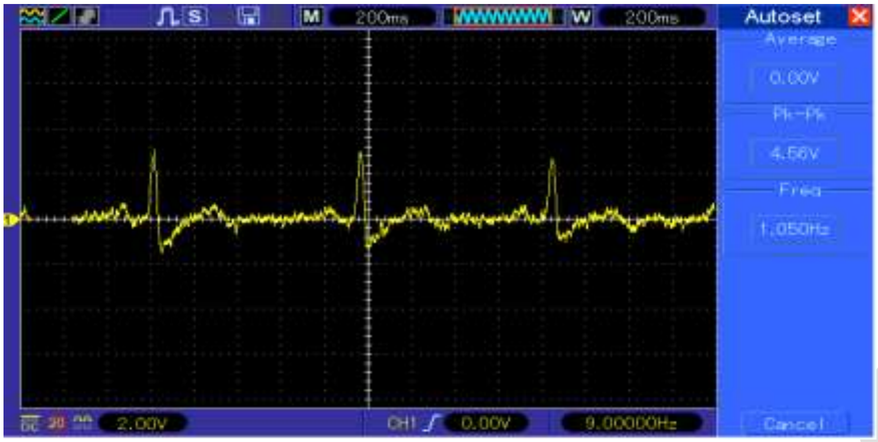

Fig 3.1: ECG waveform recorded without connecting RL Drive

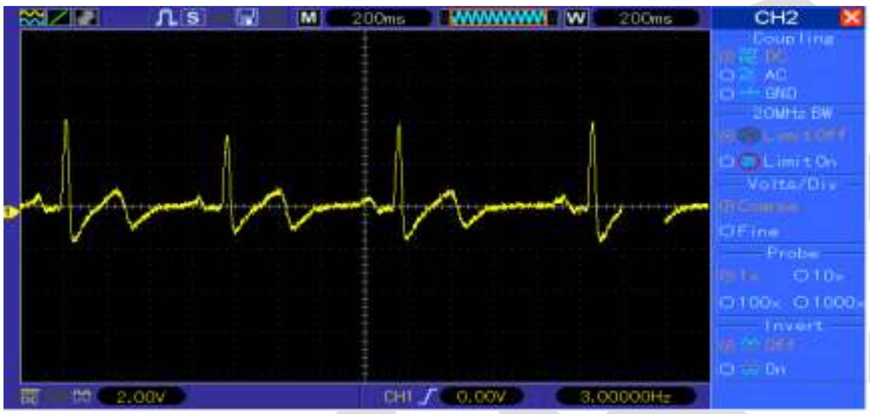

Fig 3.2: ECG waveform recorded with RL Drive included

CONCLUSION

The improvement in the clarity of ECG signal due to improvement in CMRR consequent to inclusion of RL drive circuit has been observed and recorded and the improvement in the signal Can be easily seen by comparing the waveform shown in fig 4.1 and 4.2.The ground isolation provided in the design of the ECG amplifier circuit would assure patient safety. The 'ground' in the ECG amplifier and the 'Ground 'in the section subsequent to demodulator are galvanically isolated.

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