Indian Institute of Technology
Hyderabad

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## Analog Electronics and Integrated Circuits

# Bio Signal Amplifier

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# 1 Circuit Design for ECG

The approach taken to build the instrumentation amplifier is to use two buffer circuits for the two terminals of the ECG and one difference amplifier.

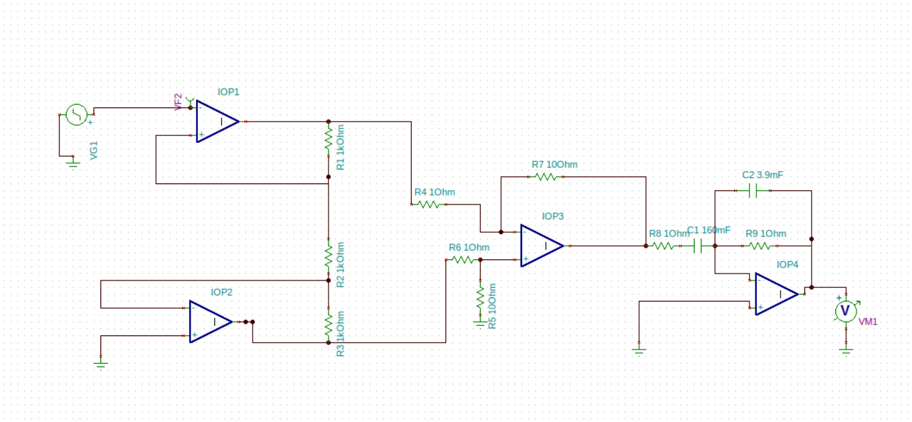


Figure 1: Circuit diagram for ECG signal amplification.

# 2 Instrumentation Amplifier Analysis

For any general $R_1$, $R_2$, $R_3$, $R_4$ of the operational amplifier, the total amplification is given by:

$$\frac{V_0}{V_1 - V_2} = \frac{R_4}{R_3}\left(1 + 2\frac{R_1}{R_2}\right)$$

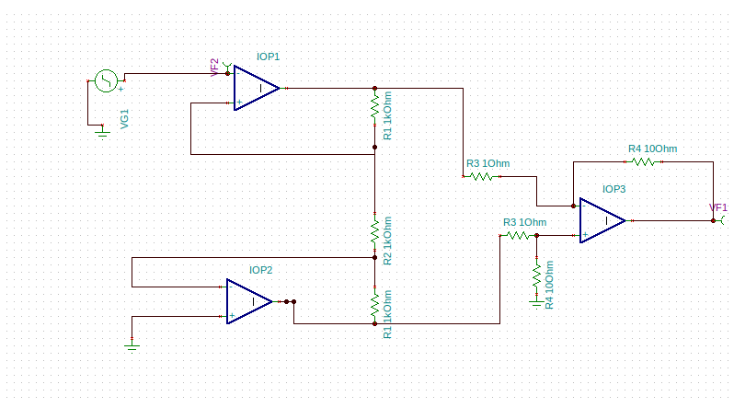


Figure 2: Instrumentation Amplifier Design.


Figure 3: Input Output Characteristics of ECG Amplifier for a general sine wave

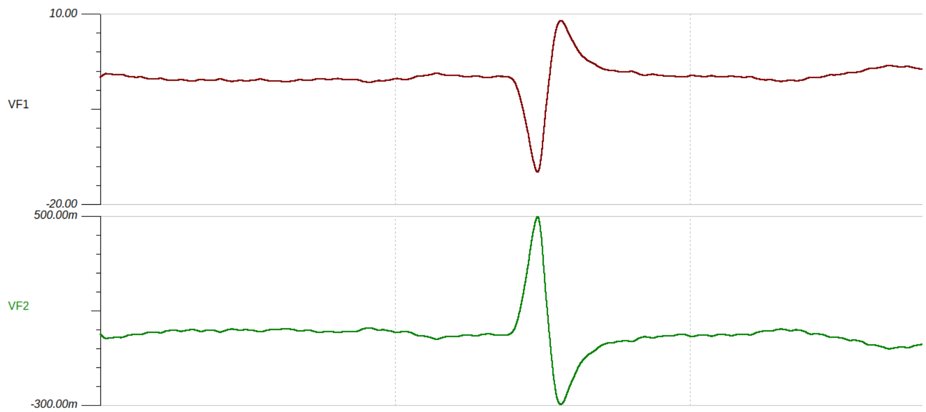


Figure 4: Input Output Characteristics of ECG Amplifier for ecg signal

The input signal has been taken from a .wav file

## 3 Amplification Analysis

**Proof:**

Amplification due to buffer

$$\begin{aligned}
v^- &= v^+ \\
v_1^+ &= V_{\text{signal}} \\
v_2^+ &= 0 \\
i_d &= \frac{V_{\text{signal}}}{R_2} \\
V_{o1} &= V_{\text{signal}}\left(1 + \frac{R_1}{R_2}\right) \\
V_{o2} &= V_{\text{signal}}\left(-\frac{R_1}{R_2}\right)
\end{aligned}$$

Amplification due to difference amplifier

$$-\frac{R_4}{R_3}(V_{o1} - V_{o2})$$

Therefore, the net amplification is given by

$$\text{Amplification} = \frac{R_4}{R_3}\left(1 + 2\frac{R_1}{R_2}\right)$$

Signal being amplified: ECG (5mV)
$R_1 = R_2 = 1\,\mathrm{k\Omega}$
$R_4 = 1000R_3$
Net Gain = 3000

Note: $R_4/R_3 = 10$ (as the .wav file has an amplitude of 500mV)

# 4 Filter Analysis

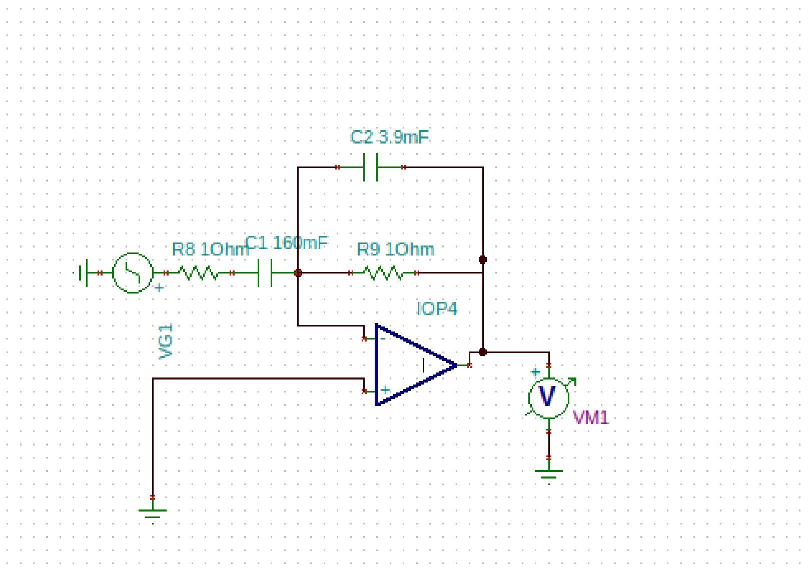


Figure 5: Filter Design

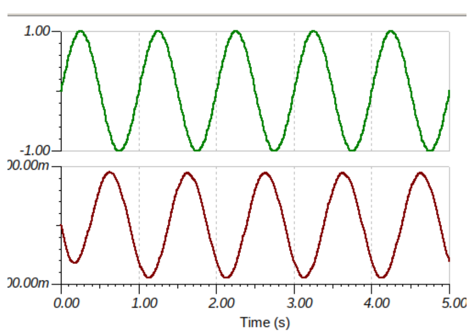


Figure 6: Input Output Characteristics at f=1Hz

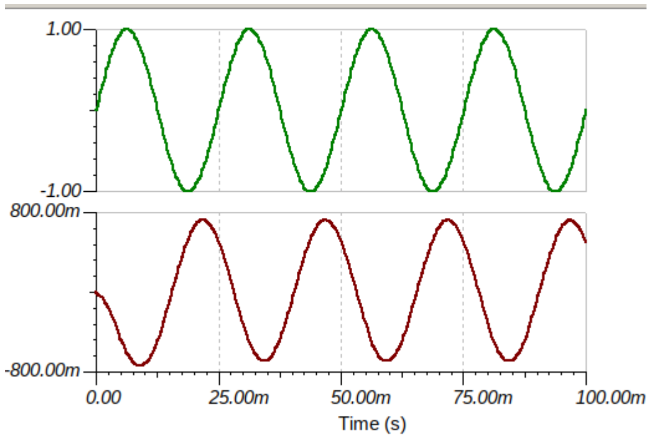


Figure 7: Input Output Characteristics at f=40Hz

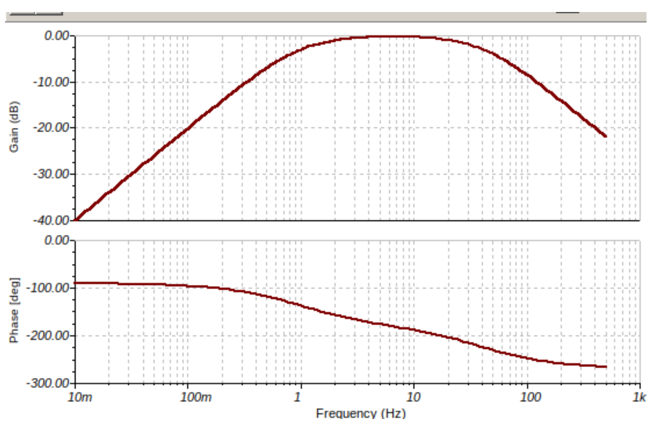


Figure 8: Bode Plot of the Filter Circuit

The circuit is designed such that

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

For the given values:

$$f_0 = 6.32\,\text{Hz} \quad f_l = 1\,\text{Hz} \quad f_h = 40\,\text{Hz}$$

As depicted 1Hz and 40 Hz are the half power frequencies where the output wave is 0.707 times the input wave

## 5 Transfer Function

$$v_{\text{in}} - iR_1 - \frac{i}{C_1 s} - \frac{i}{C_2 s(1 + C_2 s)} = V_0$$

$$i = \frac{v_{\text{in}}}{R_1 + \frac{1}{c_1 s}}$$

on solving we get

$$H(s) = -\frac{c_1}{c_2} \cdot \frac{1}{(R_1 C_1 s + 1)(R_2 C_2 s + 1)}$$

This equation describes the relationship between the input ($v_{\text{in}}$) and output ($V_0$) signals in the High Pass filter circuit.

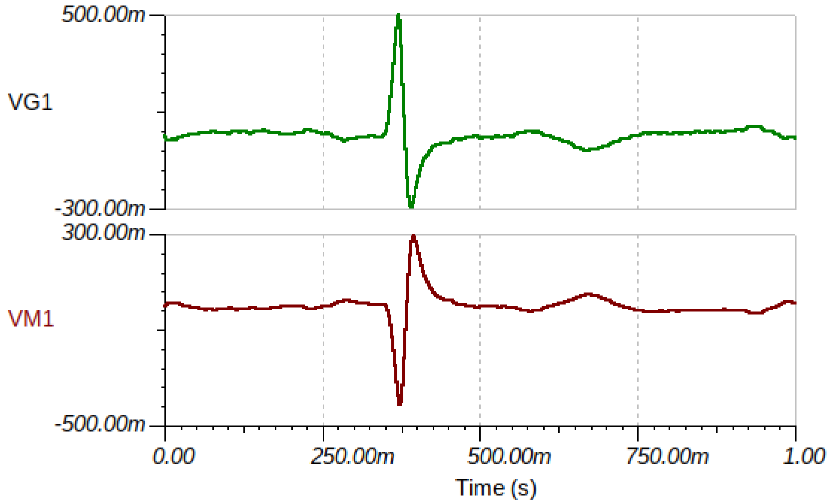


Figure 9: ECG signal before and after filtering

# 6 Final Implementation

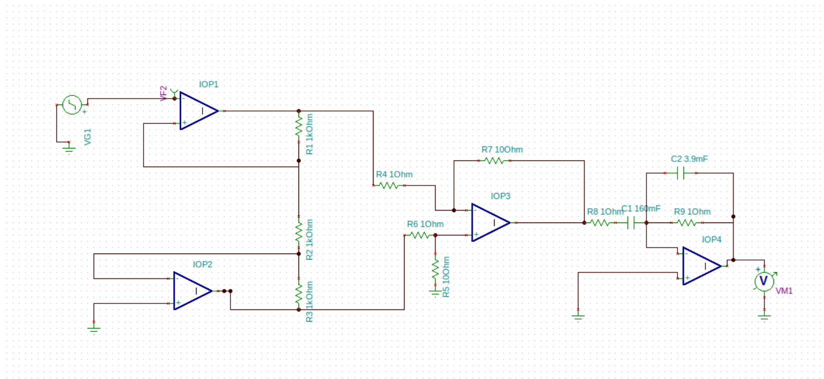


Figure 10: Circuit including Instrumentation Amplifier and Filter

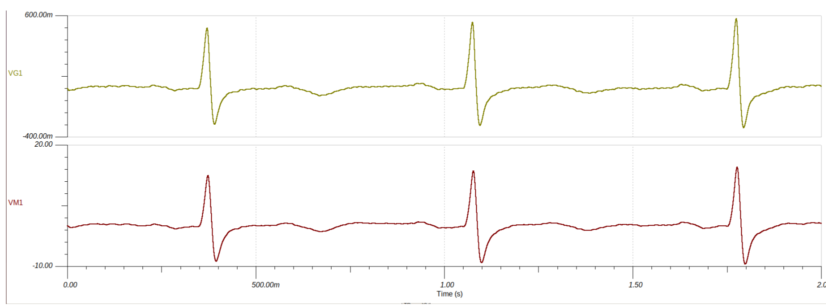


Figure 11: Circuit including Instrumentation Amplifier and Filter

interestingly we can calculate the time period of the heart beat which in this case is 0.7s which is close to the ideal value of 0.833s

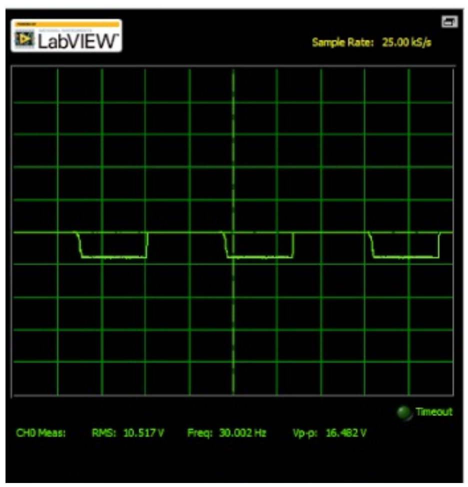


Figure 12: Output Characteristics of output wave for sine wave of amplitude 0.025 V