Recommendation to Replace High Pass Filter with Inverting Operational Amplifier Circuit in Electriocardiograph Devices

Joseph Pourtabib

Writer's Comment: For the second paper of my UWP 102E course, I was instructed to take an old lab report from a past engineering course and repurpose it for the industry setting. I decided to take circuit data and imagine a scenario in which a bioengineering company was exploring several circuit designs for measuring a human's electrocardiograph (ECG) signal. The ECG is a diagnostic tool used to assess the electrical activity of the heart and can also be used in the clinical setting to diagnose cardiac disease. Because I'm an undergrad Biomedical Engineer student eager to work in the field of medical diagnostics, this assignment resonated with me. The challenging part of this paper was to integrate the lab report into the industry setting, as there are many employees in the company who may need to read such a report but who may not be able to understand its technical concepts. I hope readers can use this report to understand the philosophy of writing for a professional setting versus writing for an academic setting.

Instructor's Comment: Joseph Pourtabib wrote this solidly carpentered project report for my Fall 2017 section of UWP 102E: Writing as an Engineer. The challenge of writing an effective formal project report adheres in the necessity of designing a document that can effectively address the divergent needs and knowledge levels of a workplace audience at once multiple and disparate. As Joe's memo header and audience analysis make clear, his workplace colleagues who will receive this report include expert, lay, executive, and technician audience members. Joe has skillfully designed his document in such a way that each of these different audiences can readily zero in on the *specific information pertinent to him or her and—no less important in a busy workplace venue—appropriately disregard information of concern only to other audience members with different organizational roles and responsibilities. In so doing, Joe, a biomedical engineer, demonstrates that he has successfully transcended the creaky student-writing-for-TA paradigm and now stands prepared to design documents that can get things done in the world of working professionals.*

—Victor Squitieri, University Writing Program

DAVIS ENGINEERING ASSOCIATES

Abstract

Joseph Pourtabib. "Recommendation to Replace High Pass Filter with Inverting Operational Amplifier Circuit in Electrocardiograph Devices." Davis Engineering Associates, Biomedical Team. October 31, 2017.

On October 10, 2017, Thomas Jones, Head Engineer of the Biomedical Team at Davis Engineering Associates (DEA), tasked the junior engineers with designing an inverting operational amplifier (op-amp) circuit. The team designed and tested an inverting op-amp circuit to determine if it could replace the high pass filter in the current electrocardiograph-detecting instrument (ECGDI) prototype. The objective of this test was to consistently observe an amplification of -10 from the circuit—an amount that would be appropriate for amplifying a weak ECG signal into a signal that could be processed and interpreted. The results of the test show that the designed inverting op-amp circuit is capable of regularly achieving the specified gain of -10. Based on these results, the biomedical team recommends that DEA replaces the high pass filter with an inverting op-amp circuit for future ECGDI prototypes.

Davis Engineering Associates

Memorandum

October 31, 2017

To: Thomas Jones, Head Engineer, Biomedical Team

From: Joseph Pourtabib, Junior Engineer, Biomedical Team

Subject: Recommendation to Replace High Pass Filter with Inverting Operational Amplifier Circuit in Electrocardiograph Devices

Distribution: Andy Evans, Director of Product Design
Julia Clark, Director of Project Finance
Bryan Smith, Product Test Lab Technician

During the weekly board meeting on October 10, Thomas Jones, the Head Engineer of the Biomedical Team, assigned a project to the junior engineers to design an inverting operational amplifier (op-amp) circuit. The inverting op-amp circuit was tested to determine if it was capable of consistently amplifying a weak signal. Based on the results of this test, the Biomedical Team decided that the inverting op-amp circuit was a feasible replacement for the high pass filter in the current electrocardiograph-detecting instrument (ECGDI) prototype. This report provides the background of the project, gives the design of the current ECGDI prototype, illustrates the desired inverting op-amp circuit, outlines the method used to test the circuit, analyzes the results, and recommends that Davis Engineering Associates replaces the high pass filter with an inverting op-amp circuit for future ECGDI prototypes.

Background of the Project

On October 10, 2017, Davis Engineering Associates (DEA) met to discuss the current state of the company's electrocardiograph-detecting instrument (ECGDI—SN#753089). The purpose of the ECGDI is to take a user's ECG signal and process the signal so that the user can monitor their heart's electrical activity. During the meeting, the Product Test Team announced that the latest prototype of the ECGDI was having issues detecting any signals from the user's body. They suggested that because the ECG signal is extremely weak—anywhere from 0.1-5 mV on average—the prototype circuit must contain an amplifying component for the user's signal. Upon hearing the announcement from the Product Test team, Thomas Jones, the Head Engineer of the Biomedical Team, tasked the junior engineers with exploring solutions containing an inverting operational amplifier. The junior engineers of the biomedical team began working on project Inverting Op-Amp Implementation (Project #75B) shortly after the meeting adjourned.

Design of the Current ECGDI Prototype

The current electrocardiograph-detecting instrument (ECGDI) prototype contains a three-stage circuit beginning with a detector for the user's ECG signal, followed by a high pass and low pass filter (stages two and three, respectively) used to erase any interference in the signal. Figure 1 illustrates this three-stage circuit.

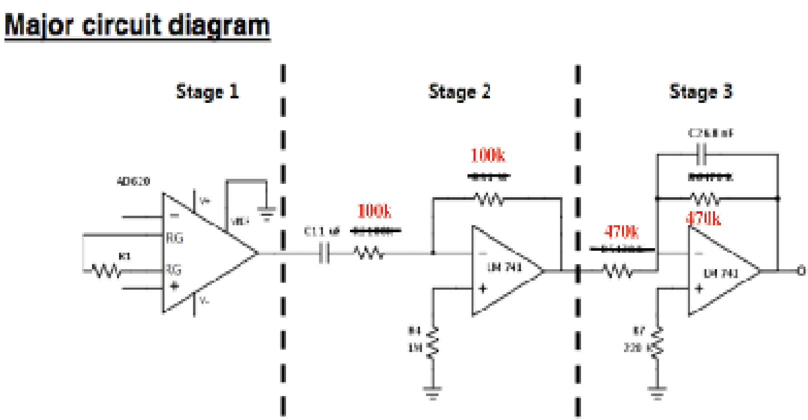

Figure 1. Current ECGDI Prototype Circuit [1].

In each of the filter stages, both resistors (denoted by the zig-zag lines) contain the same value; stage 2 contains 100 k-ohm resistors and stage 3 contains 470 k-ohm resistors. Because each stage contains resistors with the same values, the filters will not amplify the input signal—their sole purpose is to filter out noise. There is also a derived equation that denotes the gain (or amount of amplification) of both of these filters.

$$A = -(R_f/R_i) \quad (1)$$

Where:

A = Gain of the Circuit
R_f = Resistance of the Feedback Resistor in Ohms
R_i = Resistance of the Input Resistor in Ohms

Plugging in the resistance values for both stages 2 and 3 yields a gain of 1, so the magnitude of the signal entering stage 2 will equal the magnitude leaving stage 3.

Illustration of the Proposed Inverting Operational Amplifier Circuit

The Biomedical Team was assigned to design an inverting op-amp circuit to replace the passive high pass filter in stage 2 of the current ECGDI prototype. In an inverting op-amp circuit, the input signal is connected to the inverting node of the op-amp (denoted by the negative sign) and the output of the op-amp is determined by the selection of resistance values (namely Ri and Rf). Figure 2 illustrates the most basic form of an inverting op-amp circuit.

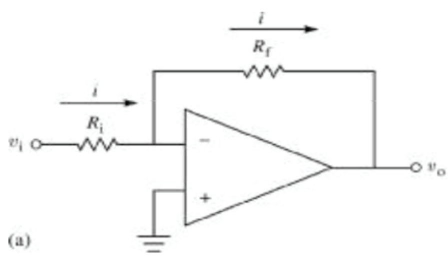

Figure 2. Inverting Operational Amplifier [2].

The gain of the inverting op-amp circuit is the exact same as the gain denoted by Equation (1). With this information in mind, the Biomedical Team designed a circuit with a gain of -10 (large enough for signal amplification) by setting the value of Rf to be 100 k-ohm and the value of Ri to be 10 k-ohm.

Testing the Inverting Operational Amplifier Circuit

The Biomedical Team tested the inverting op-amp circuit to see if it could consistently yield a gain of -10. The configuration in Figure 2 was assembled on an ELVIS prototyping board connected to a computer. The input of the circuit was then connected to a variable power supply, which was controlled by the computer. An oscilloscope was also connected to the input and output of the circuit to monitor the output voltage in relation to the input voltage. After turning on the variable power supply (input voltage of the circuit), the Biomedical Team recorded the output voltage displayed on the oscilloscope. The output voltages recorded corresponded to an input voltage range of -0.5 V to 0.5 V measured in 0.1 V increments.

Inverting Operational Amplifier Testing Results

The inverting op-amp circuit did not suffer any malfunctions while the results were generated. Similarly, there were no issues with the ELVIS prototyping board, the oscilloscope, the variable power supplies, or the computer.

Table 1 shows the output voltage and gain for each input voltage.

Input Voltage (V)	Output Voltage (V)	Gain (Output / Input)
-0.5	4.928	-9.856
-0.4	3.903	-9.758
-0.3	2.896	-9.653
-0.2	1.882	-9.41
-0.1	0.862	-8.619
0	-0.170	Not a Number*
0.1	-1.315	-13.15
0.2	-2.082	-10.41
0.3	-3.028	-10.093
0.4	-3.973	-9.9325
0.5	-4.912	-9.824

Table 1. Output Voltage Readings from Oscilloscope.
**The gain cannot be computed because of division by 0.*

Analysis of Test Results

The first thing to address with the data is the abnormal reading for the input voltage of 0 V. The output voltage for the circuit should have also been 0 V, but sometimes the op-amp can have an offset voltage due to input resistances. Essentially, the op-amp can create a negligible voltage only when the input voltage is 0 V. Aside from that abnormal reading, most of the readings hovered around a gain of -10—except for the small input voltages of 0.1 V and -0.1 V. After examining all the data, the Biomedical Team concluded that the inverting op-amp circuit was capable of amplifying a weak signal and would therefore be an appropriate replacement for the high pass filter in the ECGDI prototype.

Recommendation to Replace High Pass Filter with Inverting Operational Amplifier Circuit

The Biomedical Team strongly recommends replacing the passive high pass filter used in the current electrocardiograph-detecting instrument (ECGDI) prototype with an inverting operational amplifier (op-amp) circuit. As demonstrated by the test results, the inverting op-amp circuit is capable of achieving a gain necessary to amplify the weak ECG signal into a detectable output. The Biomedical Team believes the Product Test Team will have no problems testing the device to detect an ECG signal after implementing the inverting op-amp circuit.

In addition to creating a more effective ECGDI, the circuit replacement will not affect the cost of manufacturing ECGDI products. The Biomedical Team replaced the high pass filter with the inverting op-amp circuit by switching the input 100 k-ohm resistor in stage 2 of Figure 1 with a 10 k-ohm resistor. Essentially, the current and proposed circuits are the same, except one resistor has been replaced by a lower-valued resistor.

If this circuit proposal is approved, the next step for Davis Engineering Associates (DEA) should be to take the ECGDI prototype to the Product Test Team for quality assurance. The Product Test Team caught the signal amplification issue with the current prototype and is more than capable of giving the final approval before DEA brings the product to market. If the ECGDI products are brought to market, Davis Engineering Associates could become a major supplier in the rapidly growing market for diagnostic medical devices.

The Biomedical Team hopes that this memo can help management reach a decision. If there are any questions or suggestions, the team can be reached via email at 530DEA.bteam@gmail.com or contacted directly in the east wing of the headquarters.

JP/gz

References

[1] T. Pan. *BIM 111 Lab 3: Electrocardiography/ECG*. University of California, Davis, Fall Quarter, 2017.

[2] J.G. Webster. "Amplifiers and Signal Processing." *Medical Instrumentation*, 4th ed. Hoboken: Wiley, 2009, p. 94.