Physiological Signal Processing Laboratory

for Biomedical Engineering Education

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Abstract—**The proposed Physiological Signal Processing Laboratory incorporates important new concepts to further its utility as a vehicle for biomedical engineering educational use. The Laboratory incorporates the physical construction, testing and analysis of eight signal processing circuit modules, introduced as lessons. Each module can be characterized through measurement with a BIOPAC MP35 data acquisition system and a student-built square wave generator. The modules are combined sequentially to create a sophisticated and functional electrocardiogram (ECG) amplification and processing system. By the final lesson, the completed ECG Signal Processor will provide meaningful outputs from signals sourced from the student's own body. Through the application of a single, easy-to-use data acquisition system and associated software to a breadboard circuitry laboratory, students can build, test and analyze signal processing modules, verify their performance against mathematical simulation using graphical comparisons, combine modules, collect physiological signals sourced from their own bodies, and evaluate the results. By developing the complete ECG Signal Processor, module by module (as eight lessons), students develop an understanding of system design and development methodologies. In addition, when collecting data directly from their own bodies, students' curiosity is stimulated to create an environment more amenable to inquiry-based learning.**

Keywords—**signal processing, breadboard, inquiry-based, laboratory, circuit design, physiology, filters**

I. INTRODUCTION

The proposed Physiological Signal Processing Laboratory for biomedical engineering (BME) education is an evolution of the BME Laboratory introduced in 2003 by BIOPAC Systems, Inc. This evolution incorporates new understanding resulting from extensive teaching laboratory use of the previous Laboratory. The evolved elements in this Laboratory include improvements in: circuit stimulation methodology; filter analysis techniques; module development strategy (practical order for an educational setting); laboratory support (written materials provide clear introductions and module theory of operation).

Practical laboratory experience, guided by a modular development approach, is important and meaningful for the BME student. The Laboratory goal of building, testing, and analyzing a complete ECG amplification and processing system capable of processing the student's own electrocardiogram signal promotes curiosity and supports an inquiry-based approach to BME education.

Inquiry-based learning is a student-centered, active learning approach focused on questioning, critical thinking and problem solving. Inquiry-based education is characterized by a learning environment structured to create opportunities for students to be engaged in active learning based upon their own questions. Involvement in learning implies the students are developing capabilities and perceptions that permit them to look for solutions to problems during the course of acquiring knowledge.

This Laboratory addresses the challenge of teaching certain fundamentals of physiological signal processing related to biomedical engineering and promotes the concept that student inquiry implies involvement that leads to understanding. The involvement must result in developed capabilities and perceptions, for the students' inquiries to be meaningful and lead to further understanding, for inquiry-based learning to thrive.

The Laboratory incorporates several concepts critical for developing student capabilities and perceptions to support inquiry-based learning in the area of physiological signal processing. The Laboratory incorporates the physical construction and testing of a variety of simple signal processing circuit modules, each introduced as a lesson. The characteristics of each module can be easily determined through measurement with a BIOPAC MP35 data acquisition unit (Fig. 1) and associated Laboratory software (BSL *PRO*). Over the eight Laboratory lessons, students progressively build, module-by-module, a complete physiological signal processing system. By the end of the lesson series, students can employ the electrical signal detected from their own hearts (via skin surface potentials) as the signal source for the ECG Signal Processor, which provides useful outputs and features such as clinical ECG, hum rejection, and QRS wave detector. In the process of building this system, students learn:

- practical issues associated with signal processing module (circuit) construction and testing
- the importance of stable signal generation and measurement for circuit analysis
- tools and methods useful for circuit analysis, including transfer functions and circuit simulation
- the relationship of any single processing module to the complete system

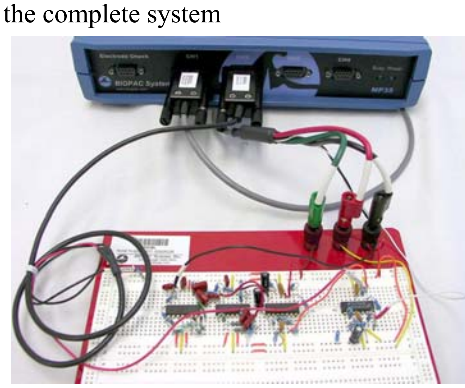

Fig. 1: BIOPAC MP35 and SS39L Breadboard

The BIOPAC MP35 data acquisition unit, BSL *PRO* software and SS39L Breadboard are sufficient to permit students to complete the Laboratory. The BIOPAC MP35 unit is used to perform one or two channel storage scope measurements and supply power to the breadboard. The MP35 unit is certified to IEC60601-1 medical electrical safety standards and provides a double fault protected, galvanically isolated, current-limited ±5 Volt power supply to the SS39L breadboard. Students use the BSL *PRO* software for circuit data collection, analysis, and simulation, thus reducing the amount of time the teacher needs to spend on software training.

II. METHODOLOGY

The Laboratory is modular and creates a foundation that empowers students to create different types of physiological signal processing systems beyond the assigned ECG Signal Processor. The signal processing circuit modules introduced in this Laboratory can be combined in a variety of ways to build a number of different real-world physiological signal processing systems, such as amplifiers and processors for signals originating from the muscles (EMG), eyes (EOG), stomach (EGG), and brain (EEG).

The signal processing circuit modules are fundamental processors, largely orthogonal in practical operation. Depending on how modules are combined and modified, systems using similar modules can perform considerably different physiological processing operations. For example, the detector topology for R-wave detection in the ECG becomes (with slight modification) an Alpha wave indicator when recording the EEG.

Signal processing circuit modules are introduced sequentially to students as lessons. Students build the modules on a breadboard, evaluate the circuit module characteristics and compare results to mathematical simulation using the BIOPAC MP35 data acquisition unit and BSL *PRO* Laboratory software. Comparisons between collected and simulated data can be performed in real time and in a graphical manner.

The Laboratory introduces eight fundamental signal processing circuit modules (lessons) to the student (Figs. 2-9) and culminates in an ECG Signal Processor (Fig. 10)—ECG Amplifier with Hum Rejection and QRS Detector.

The students begin the Laboratory series by building, testing and analyzing a Square Wave Generator (Fig. 2). The students use this generator to help them analyze each subsequent module. The generator has a high and low level output suitable for testing the amplifiers, filters, and function blocks in the complete ECG Signal Processor.

Several of the Laboratory sessions revolve around filter design, construction, and testing (Figs. 4-7 and 9). Filter cutoff frequencies can be measured by employing a number of different methods. By measuring the filter's effect on "sag" or "tilt" for an input square wave, the filter's high pass response can be determined.

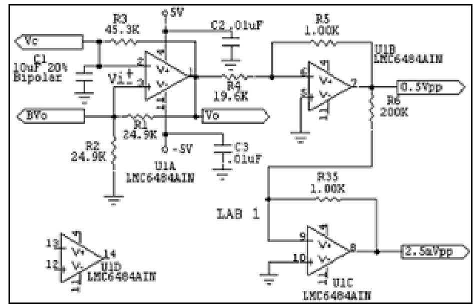

Fig. 2: Lab 1 Square Wave Generator

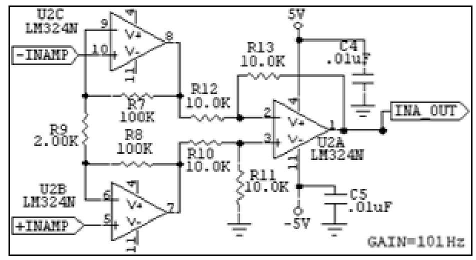

Fig. 3: Lab 2 Classic Instrumentation Amplifier

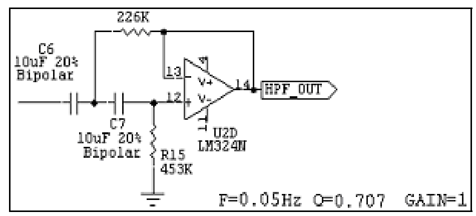

Fig. 4: Lab 3 High Pass Filter

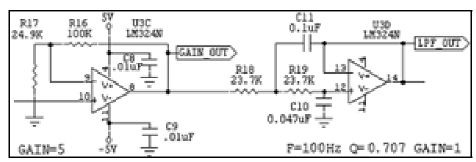

Fig. 5: Lab 4 Positive Gain Block & Low Pass Filter

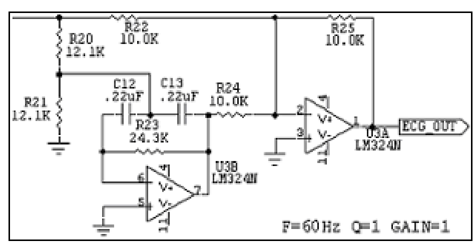

Fig. 6: Lab 5 Notch Filter

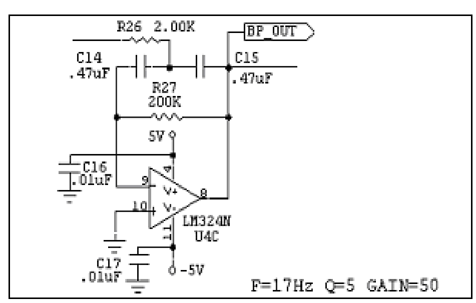

Fig. 7: Lab 6 Single Frequency Band Pass Filter

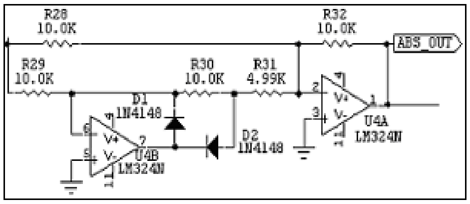

Fig. 8: Lab 7 Absolute Value Converter

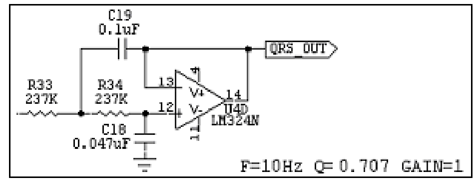

Fig. 9: Lab 8 Low Pass Filter

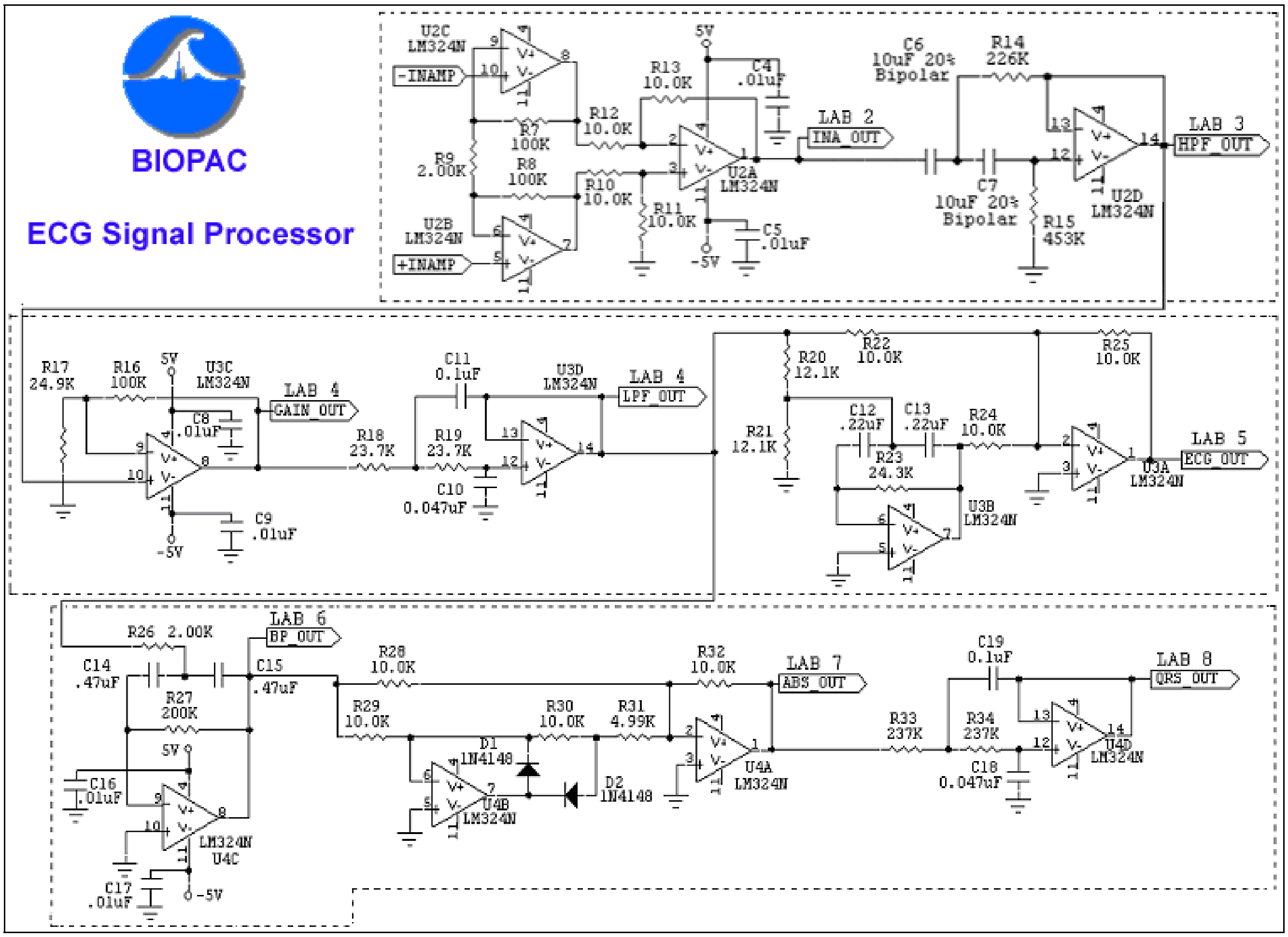

Fig. 10 ECG Signal Processor

By measuring the filter's effect on rise time of an input square wave, the filter's low pass response can be estimated. In addition, by stimulating the filter with a square wave, and using the BSL *PRO* software to perform a derivative on the filter's square wave response and then perform an FFT on the derivative result, students can produce magnitude and phase plots of the filter's transfer function.

As an additional teaching aid, the BSL *PRO* software can directly emulate (simulate) each signal processing circuit module, via simple software controls (Figs. 11-12). The physical biquad filters in the Laboratory (low pass, high pass, band pass, and notch) can be simulated in the BSL *PRO* software as 2nd order IIR filters, operable in real time or post-processing. Equivalent simulations are available for nonlinear signal processing circuits, such as the Absolute Value Converter. Expression calculations are suitable for simulating differential or single ended amplifiers.

Before any lesson, the instructor can set up the Laboratory software using a BSL *PRO* Template. Template files are used to preconfigure the BIOPAC MP35 data acquisition system for a particular lesson.

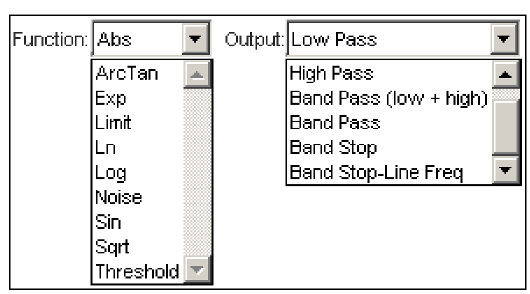

Fig. 11: Software Circuit Simulation Controls

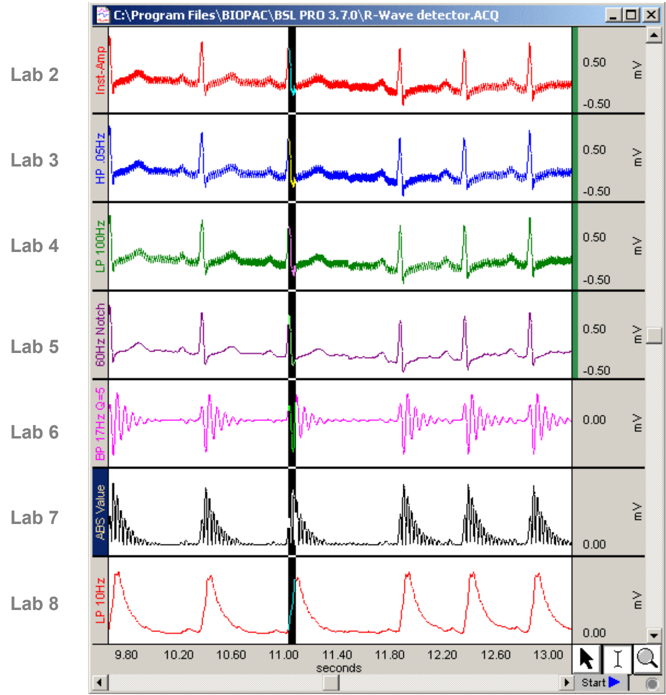

Fig. 12: Compare Actual to Simulated Results

For example, Templates can be used to configure two of the BIOPAC MP35 unit input channels as synchronized storage scope inputs, with a sampling rate of 10kHz and a recording time of 30 seconds.

Templates are used to set up acquisition modes in the MP35 system, such as: sampling rate, acquisition length, and number of channels. Templates include a text "Journal" that can be used to present laboratory instructions and procedures to the student and to record results. For advanced teaching applications, Templates can easily be set to include additional real and simulated processing modules.

III. RESULTS

The results of a simulation that identifies the nature of the signal at the output of each processing circuit in the ECG Signal Processor are illustrated in Fig. 12. In this graph, a real ECG signal is amplified and then processed solely (in simulation) by the BSL *PRO* software. The data shown at the output of each simulated stage is presented in the same way and is visually identical to the actual measurement at respective points in the ECG Signal Processor physically constructed on the breadboard.

The Laboratory introduces fundamental physiological signal processing circuit modules sequentially, as lessons, allowing students to grasp the performance of each before proceeding to the following module. This method establishes a strong foundation for students to design and construct processing systems on their own.

IV. DISCUSSION

When students collect data directly from their own bodies, the process stimulates their curiosity and gives them more control over their learning by allowing them to test and retest to more fully understand the steps involved in scientific inquiry.

The "building-block" nature of the signal processing circuit modules encourages students to think of novel connection topologies between the various modules, in service to the principles of inquiry-based learning.

V. CONCLUSION

The Physiological Signal Processing Laboratory introduces fundamental signal processing modules to students, lesson by lesson, requiring them to build, test and analyze. This process facilitates the transition from instructor-dictated to student-driven learning by viscerally engaging students in an inquiry-based educational environment. Student curiosity is maintained as a consequence of building, testing, and analyzing a complete ECG Signal Processor capable of processing the student's own electrocardiogram.

The modular, "building block" nature of the Laboratory helps develop a strong foundation for additional learning. The specialized Laboratory software (BSL *PRO*) associated with the BIOPAC MP35 data acquisition unit permits students to encounter the laboratory hurdles of proper amplification, signal calibration, scaling and unit assignment, data digitization, signal processing, analysis, and simulation—without encountering the myriad set up challenges and time loss that conventional equipment can present.

REFERENCES

[1] Dauzat, M. *Manual of Practical Works—Human Physiology* (Manuel de travaux pratiques—physiologie humaine), 6th edition. France: Sauramps, 2005.

[2] Enderle J., Kelso D., Ropella K. "Preparing Biomedical Engineers for Real-World Problem Solving." *Proceedings of the Whitaker Foundation BME Educational Summit*, 2000.

[3] Fox, S. I., *A Laboratory Guide to Human Physiology: Concepts and Clinical Applications*, Tenth Edition. WCB/McGraw-Hill, 2004.

[4] Lundmark J. and Salmi, A. "Inquiry-based Labs using the BIOPAC Student Lab System:" (Results from an NSF-CCLI grant-supported project.) *HAPS Proceedings*, 2001.

[5] Macy A. "Inquiry-based Biomedical Signal Processing Laboratory: From Practice to Simulation." *Proceedings of the IEEE EMBS 25th International Conference*, 2003.
Available: http://www.biopac.com/ss39lwhite.pdf

[6] Macy A. Students as Signal Sources in the Biomedical Engineering Laboratory: *Proceedings of the IEEE EMBS 23rd International Conference*, 2001.
Available: http://www.biopac.com/studentsassignal.pdf

[7] Marieb, E.M., *Human Anatomy & Physiology Laboratory Manual*, 7th edition. Pearson/Benjamin Cummings, 2004.

[8] Pflanzer R. *Experimental and Applied Physiology: Including BIOPAC Lab Experiment,* Sixth Edition. Kendall/Hunt, 2004.

[9] Thakar N., Webster J., Tompkins W. "Estimation of QRS Complex Power Spectra for Design of a QRS Filter," IEEE Transactions on Biomedical Engineering, November 1984, pp 702-706.

[10] Wood M., *Laboratory Manual for Anatomy and Physiology*, 3rd edition. Pearson/Benjamin Cummings, 2005.