# Bioengineering 6460
# Homework Assignment
# Simulation of the ECG

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December 6, 2011

# 1   Introduction

The goal of this homework is to gain some firsthand experience with analyzing the electrocardiogram and its capabilities to detect cardiac electrical activity (without hurting anyone in the process!).

ECGSim is a program created by Adriaan van Oosterom, Thom Oostendorp, and Peter van Dam to illustrate the bioelectric field relationships in the ECG and we will use it in this assignment for some simulation experiments. The goal is to develop some understanding of how changes within the tissues of the heart alter the ECG potentials on the body surface.

Good sources of background information on ECGSim include

- The paper about ECGSIM

- The ECGSim website (www.ecgsim.org)

- The papers referred to in the online manual,[1,2,3,4,5,6] at least one of which is available on the class web site.

## 1.1   Downloading ECGSim

To download an executable version of the program, go to www.ecgsim.org/download.html and select the appropriate architecture; we will use the **older version 1.3**. There is a link for a tutorial for each of the two versions of the program.

# 2   The Assignment

Following the derivation in the first question, use ECGSim to carry out the following simulations and answer the associated questions. Document your results with figures as necessary to support your answers.

1. **Derivation of augmented leads** We have discussed the derivation and goals of the augmented leads illustrated in Figure 1 and shown graphically the associated orientation of each lead in the context of the Einthoven triangle. While the augmented leads are different from the limb leads, they are derived from them, *i.e.,* they contain no new information. Moreover, like all leads based on the Einthoven system, there is redundancy present, for example, it is possible to derive each limb lead from the other two. Thus it must be possible to express the augmented leads from the limb leads and the lecture notes contain one form of such expression, repeated here as

$$
\begin{aligned}
aVL &= V_I - \frac{1}{2}V_{II} \\
aVF &= V_{II} - \frac{1}{2}V_I \\
aVR &= -\frac{1}{2}(V_I + V_{II})
\end{aligned}
\tag{1}
$$

Based on the information in Figure 1 and application of Kirkoff's Laws in the resulting simple circuits, derive the three expressions above for each of the augmented leads. Make sure to include enough intermediate steps to indicate the path you have taken.
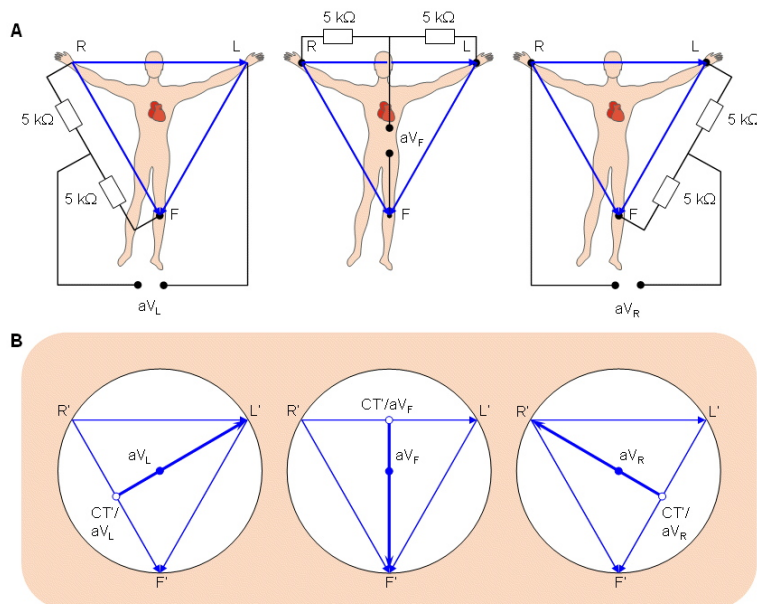
Figure 1: Recording arrangement for augment ECG leads. Upper panel shows the schematic measurement circuit and the lower panel illustrates the locations of the leads in the Einthoven triangle.

2. **Simulation of ectopic focus**

    (a) Select a node high on the left lateral free wall (left side of the left ventricle) and assign it to be the site of a focal or ectopic beat using the Membrane:Focus menu. At first, use the "Replace" option and document the resulting epicardial activation time and potential distribution and the body surface, *i.e.,* ECGs and body surface maps. How do the ECGs signal shapes change?

    (b) Now switch to "Merge" mode in the Membrane:Focus menu and observe the effect of turning the ectopic beat on and off. Also vary the timing of the ectopic beat and note the effect.

    (c) Which of these two scenarios best mimics the Wolff-Parkinson-White (WPW) syndrome in humans? Based on the simulation results, can you devise possible schemes for identifying WPW based on the surface ECG and the body surface maps? Do you think these criteria are unique, *i.e.,* can identify the situation in a way that is unambiguous? Can you picture an equivalent source for this condition?

3. **Transfer function and lead sensitivity** Wilson developed the precordial electrodes to provide more regional sensitivity than is possible with the limb leads, *i.e.,* he wished to localize in the heart where abnormalities were occurring. We will use ECGSim to see if these leads are, indeed, spatially sensitive and thus meet the desired goal.

    (a) Read about the transfer function in the manual under Thorax:Surface Function:Transfer Function and in the class notes on the Forward Problem so you understand the concept behind it. We will use it to evaluate the spatial sensitivity of the precordial electrodes.

    (b) Display the transfer function on the heart surface for each of the precordial leads in turn and answer the question of whether each is, indeed, sensitive to particular regions

of the heart. For each precordial lead, describe and show with figures such regions of sensitivity and interpret the meaning of the color (amplitude and polarity) of the transfer coefficients. Note that ECGSim allows the user to select scaling for the display of the transfer function coeefficients so experiment with these settings before drawing conclusions about the relative sensitivity of the different leads.

(c) For the lead you consider the best example of what Wilson had in mind, *i.e.,* where there is the most selective sensitivity, create a local abnormality in the heart surface potentials, *e.g.,* a zone with altered action potential amplitude or baseline or abnormal repolarization, and demonstrate that this abnormality does, indeed, appear in the ECG for that particular precordial lead.

(d) Can you think of any caveats to this whole analysis, anything that could reduce the generality of your findings or alter your conclusions.

# 3   The Report

Structure the report with the following components:

1. Introduction: what are the goals of the assignment? What is the basic background required to appreciate the results? (0.5–1 page)

2. Methods: briefly describe the software you used, any other tools that were handy to produce, gather, or analyze results. (0.5–2 pages)

3. Results and Discussion: organize these around the questions in the assignment. Include discussion of those results in the relevant sections.

4. Conclusions: summarize what you have gained from the assignment and other general observations about the use of electrocardiography and its sensitivity to electrical events in the heart.

Guidelines for the assignment:

• Imagine your fellow classmates as the primary audience for your reports—I know the answers and want to help you develop your ability to explain them to each other.

• Make sure to include content in each section described above.

• Typeset all equations using whatever tools you like—engineers must be able to use equations to get answers and to convey ideas as part of our language.

• All figure captions should follow the standard format, *i.e.,* include a figure number, a brief description that works almost like a title, and then the details necessary for the reader to understand and appreciate the content. Make sure to label all axes and add to the figure all text, arrows, or whatever is useful to convey your message.

• Treat this as formal scientific prose, just like a lab report or a journal article or grant proposal. Use appropriate grammar and conventions, including a bibliography and citations.

Note that the idea here is to use the model to explore questions and different students will generate different answers depending on which combination of parameters get set to which values. There are many correct answers and so it is necessary to explain and defend each answer based on the data from the simulation. Try and base all your statements on the simulation data and describe or show examples of those data to support your arguments. Even a perfect description of, for example, what happens in WPW, is not the goal of the exercise unless there are data from the simulation to support that description.

Note too that the model does not have a conduction system (nor any atria), so any explanations based on the role of the HIS-Purkinje system will be questionable when explaining the response of the model.

**Please have the reports either sent to me as pdf files or delivered in paper form to my office in the SCI Institute (4602 WEB) by Friday, December 16, at 2:00 PM.**

# References

[1] A. van Oosterom. Interactive simulation of the QRS wave forms. In Y. Kim and F.A. Spielman, editors, *Proceedings of the IEEE Engineering in Medicine and Biology Society 11th Annual International Conference*, pages 183–184, 1989.

[2] A. van Oosterom, G. Windau, and G.J.M Huiskamp:. Simulation on a PC of the QRS-T wave forms. In P.W. Macfarlane and P. Rautaharju, editors, *Electrocardiology '93*, pages 97–100. World Scientific, 1994.

[3] G.J. Huiskamp and A. van Oosterom. The depolarization sequence of the human heart surface computed from measured body surface potentials. *IEEE Trans Biomed. Eng.*, 35:1047–1059, 1989.

[4] G.J.M. Huiskamp and A. van Oosterom. The effect of torso inhomogeneities on body surface potentials. *.J. Electrocardiol.*, 22:1–20, 1989.

[5] J.J.M. Cuppen and A. van Oosterom. Model studies with the inversely calculated isochrones of ventricular depolarization. *IEEE Trans Biomed. Eng.*, 31:652–659, 1984.

[6] A. van Oosterom. Genesis of the T-wave as based on an equivalent surface source model. *.J. Electrocardiol.*, 34(suppl):217–227, 2001.