**BioE 101: Instrumentation in Biology and Medicine**

**Spring 2019**

Instructor: Frankie Myers, PhD (fbm@berkeley.edu)

Office Hours: 3:30 – 4:30 (after class), 340 HMMB

GSIs: Quincy Huynh (quincy.huynh@berkeley.edu),

Arda Ozilgen (arda.ozilgen@berkeley.edu)

Lecture: 9 Lewis Hall, Tues/Thurs 2:00 – 3:30

Labs:

Tues 10:00 – 12:00, 430 HMMB (Arda)

Thurs 11:00 – 1:00, 430 HMMB (Quincy)

Fri 3:00 – 5:00, 430 HMMB (Arda + Quincy)

Prerequisites: Math 53, 54; Physics 7A-B,

Course Description: This course teaches the fundamental principles underlying modern instrumentation used in biology and medicine. The course takes an integrative analytic and hands-on approach to measurement theory and practice by presenting and analyzing example instruments currently used for biological and medical research (e.g. ECG, MRI, pulsed oximeters, flow cytometers). Rather than covering each instrument in detail, we will stress the common design tradeoffs that you will face while designing an instrument that must meet certain application requirements. We will cover the fundamentals of characterizing signals and instruments, including signal-to-noise ratio, contrast and dynamic range, bandwidth, resolution, sampling rate, bit depth, common mode rejection, etc. We will discuss design considerations related to minimizing noise and interference, both from a practical standpoint (e.g. strategies for noise matching with instrumentation amplifier circuits) and a theoretical standpoint (e.g. modeling capacitive coupling mechanisms from 60Hz power lines). You will understand the basic building blocks of an instrumentation system: sensor transducers, preamplifiers, anti-aliasing filters, analog-to-digital converters, and digital signal processing algorithms. We will also discuss the practicalities of working within the medical device industry, including FDA oversight, working within a quality system, complying with standards and regulatory guidance, and risk management. We will cover the translational terminology that engineers must understand to work with their customers, medical doctors and laboratory researchers. In the hands-on labs, you will build several working instruments using breadboards, oscilloscopes, Arduino microcontrollers, and data analysis in Python.

Course Objectives: At the end of the course, you should understand the architecture and design principles of modern biomedical sensor data-acquisition systems. You should understand how to choose the appropriate biomedical sensor, instrumentation amplifier, number of bits, sampling rate, anti-aliasing filter, and DAQ system. You will be able to design and build a low-noise instrumentation amplifier circuit. The laboratories and the final design project enable you to practice hands-on skills related to prototyping: soldering, debugging, using test equipment, navigating parts catalogs and spec sheets, working with microcontrollers, and interfacing with Python.

Grading:

Weekly Homework (9)………...…....15%

Midterms (2)………………………...50%

Labs (5)……..……………………….15%

Design Project……………………….15%

Class Participation…………………...5%

Your lowest homework grade will be dropped from the final calculation.

**Homework:**

Homeworks are due on bCourses before beginning of class on Tuesdays.

We simply cannot accept late homework because we want to be able to post solutions ASAP. Your lowest homework grade will be dropped, so missing one will not have a significant impact on your homework average.

As stated above, the lowest homework grade will be dropped so missing one will not have a significant impact on your homework average.

**Lab Write-ups:**

Lab write-ups are due on bCourses by start of following lab period.

Late labs may be accepted with a 20% penalty. If labs are more than 1 week late, they will not be accepted.

Cheating Policy: If you are caught cheating on any homework assignment or lab, you will get an automatic F (0%) on that assignment. If you are caught cheating on a midterm or design project, you will get an automatic F in the course. In either case, you will be reported to the office of student conduct. You may be expelled from the university for cheating. It’s a big deal. Don’t do it.

Regrade Policy: Regrade requests for any assignment must be submitted in writing to the GSIs within 7 days of grades being posted. A regrade request form is available on bCourses.

Reading (on reserve in Engineering Library):

There is no required textbook for the class and lecture notes will be posted. The following references are recommended for supplemental reading.

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| Title | Topics | Availability |
| Signals, Systems, and Circuits for Bioengineers (Semmlow, 3rd ed) | Most closely matches what we cover in this course, but is light on circuits.  Noise, SNR, dB, fourier transform, transfer function and frequency response, convolution and impulse response, RLC circuits, phasors, op-amps and active filters | Free eBook available from Library  On Reserve in Engr. Lib. |
| Electrical Engineering: Principles and Applications  (Hambley, 4th ed) | General circuits intro with good coverage of digital concepts.  RLC circuits, phasors, op-amps and active filters, binary and boolean logic, digital sampling, aliasing, CMRR | On Reserve in Engr. Lib. |
| The Art of Electronics (Horowitz & Hill, 3rd ed) | Bible of electronics with lots of examples of good circuit design, comparison of actual devices, and deep discussion of tradeoffs.  Active filters, amplifier noise, instrumentation amps, CMRR, low-noise design, whetstone bridge, transducers | On Reserve in Engr. Lib. |
| Practical Electronics for Inventors (Scherz, 4th ed) | Accessible handbook covering analog and digital electronics fundamentals and practical prototyping.  Oscilloscopes and test equipment, prototyping tools, PCBs, digital electronics | Free eBook available from Library  $24 on Amazon! |
| Analysis and Application of Analog Electronic Circuits to Biomedical Instrumentation (Northrop, 2nd ed) | Advanced topics in instrumentation circuits for students who want more depth.  Biosignals, analog filter topologies, low-noise design, signal conditioning, isolation and safety, ADC methods and quantization, signal modulation. | On Reserve in Engr. Lib. |
| Medical Instrumentation (Webster, 4th ed) | Useful reference covering a wide range of medical instruments, physiological signals, and transducers.  Biosignals, transducers | On Reserve in Engr. Lib. |

The course is divided into three segments:

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| Weeks | Topics | Detailed |
| 1-5 | Measurement Theory and Design Parameters | SNR, contrast, minimal sampling rates and filtering, quantization error and minimal number of bits, accuracy, precision, bandwidth of biomedical sensors. Concepts of Fourier transforms and convolution, LTI systems, impulse and frequency response.  Midterm I |
| 6-13 | Instrumentation Circuits and Transducers | Op-amp and instrumentation amp circuit topologies, noise and interference models common in biomedical devices, noise matching and interference suppression, common mode rejection. Common transducers and their noise models.  Midterm II |
| 14-16 | Medical Device Development, Evaluation, and Regulatory Approval | FDA classification and approval pathways, quality systems, design control, risk management, navigating standards and regulatory guidance. Practical prototyping: choosing parts, reading data sheets, tools of the trade. Evaluating performance: sensitivity/specificity, LoD.  Design Project |

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| **BioE 101 Schedule** | | | | | |
| **Week** | **Dates** | **Lecture** | **Lab** | **Assignment** | **Project** |
| 1 | 1/21 - 1/25 | Course Intro, LTI Systems, Fourier Transforms |  |  |  |
| 2 | 1/28 - 2/1 | Frequency Response and Impulse Response, Convolution | Lab 0 | HW 1 (due 2/5) |  |
| 3 | 2/4 - 2/8 | Digital Sampling, Quantization, dB, Bandwidth | Lab 1 |  |  |
| 4 | 2/11 - 2/15 | Noise, SNR, Resolution |  | HW 2 (due 2/19) |  |
| 5 | 2/18 - 2/22 | Interference, Contrast, Exam Review | Lab 2 | HW 3 (due 2/21) |  |
| 6 | 2/25 - 3-1 | Wheatstone Bridge, Thevenin, RLC Circuits Review, Phasors |  | **MIDTERM 1 (2/28)** |  |
| 7 | 3/4 - 3/8 | Op-amp Circuits | Lab 3 | HW 4 (due 3/12) | **Groups Assigned** |
| 8 | 3/11 - 3/15 | Op-amp Nonidealities, Spec Sheets | Lab 4 (Spice + | HW 5 (due 3/19) |  |
| 9 | 3/18 - 3/22 | Instrumentation Amps, CMRR, Revisit Wheatstone? |  | HW 6 (due 4/4) | **Design Due** |
| 10 | 3/25 - 3/29 | **Spring Break** | | | |
| 11 | 4/1 - 4/5 | Amplifier Noise, Noise Matching | Lab 5 (EKG) | HW 7 (due 4/11) |  |
| 12 | 4/8 - 4/12 | Interference, Shielding, Safety, Exam Review |  |  |  |
| 13 | 4/15 - 4/19 | Common Transducers: EKG, Photodiodes, Strain Gauge | Lab OH for Projects | **MIDTERM 2 (4/16)** |  |
| 14 | 4/22 - 4/26 | Medical Device Development: Regulatory, Quality, Prototyping | Lab OH for Projects |  |  |
| 15 | 4/29 - 5/3 | Evaluating Device Performance: Sensitivity/Specificity, LoD | Lab OH for Projects |  |  |
| 16 | 5/9 | **Final Presentations** |  |  | **Present** |

No final exam!