Physics 3330 - Electronics for the Physical Sciences

Introduction

Modern physical measurements, communication, and computation rely on electronic hardware and instrumentation. Electronic instrumentation is used in all sub-fields of physics—condensed matter, elementary particles, nuclear physics, and atomic molecular optical physics. Electronic measurements are no less common in the other physical sciences, and are essential in many modern interdisciplinary areas such as satellite-based environmental monitoring, the experimental study of chaos, or the search for extraterrestrial life. *Electronics for the Physical Sciences* provides an introduction to electronic design and, more importantly, provides hands-on experimental experience. You will be building electronic systems from scratch, and then demonstrating that you understand how they work. You are strongly encouraged to exercise initiative in the laboratory; all of the experiments are intended to be open-ended.

Organization

So far as possible, each experiment is organized in the style of a research lab. There are eight student workstations, each consisting of a set of electronic measuring instruments. You will work in groups of one or two, using the same workstation throughout the semester but sharing it with groups belonging to the other lab sections. Individual experiments, on the other hand, are built up on circuit boards that you keep for the entire semester. This allows you to continue to work on your circuit for as long as you need to complete the work.

A course calendar showing the lab and lecture plan for the semester accompanies the syllabus. During the course of the semester, announcements will be posted on the course web page (http://www.colorado.edu/physics/phys3330) and, if needed, sent to you by e-mail. In accordance with University policy, you are required to maintain and regularly check an e-mail account. You are also encouraged to use e-mail to communicate with the instructors!

Lab Sessions

Each section has one 3-hour instructional lab per week in room G-230, supervised by your lab instructor. You must attend your scheduled lab. This is the time when you can have your plans for the experiment reviewed, you can locate all of the equipment and supplies you will need, and when you will be given last-minute advice on techniques not discussed in the lab manual.

The lab is open for unsupervised work any time the building wing is open, and when no other section is meeting. The building hours will be identical to those of the library on the 1st floor immediately below our lab—access will be via the eastern stairwell. These times are available for
you to complete unfinished experiments or to explore your own ideas. You will be given the combination to the lab door lock at the first lecture. Please do not share it with anyone not enrolled in this class, or prop the door open after unlocking it.

**LECTURES**

There will be a series of lectures given in the first part of the semester on Tuesdays and Thursdays from 1 to 1:50 in Duane G-2B47. The material includes both theoretical background for the experiments and a discussion of practical problems you may encounter. The schedule and subject matter will be handed out at the first lecture.

**OFFICE HOURS**

The office hours are for help with pre-lab problems and for hands-on help in the lab. You may seek help from any of the instructors. Office hours for each instructor are:

- **Henry Kapteyn**
  kapteyn@jila.colorado.edu
  JILA A703
  Wed 2:00-3:30

- **Ed Kinney**
  edward.kinney@colorado.edu
  Duane F219
  Mon 1:30-3:00

- **Eric Zimmerman**
  edz@colorado.edu
  Duane F435
  Mon 9:30-11:00

**WEEKLY WORK SCHEDULE**

*Before your lab section:*

- Write report on the previous week's experiment.
- Read the write-up for the next experiment in the lab manual.
- Work through the theory presented in the textbook and the manual.
- Do the pre-lab problems.

*During scheduled lab:*

- Turn in the report on last week's experiment to your instructor.
- Turn in the pre-lab problems.
- Start the experiment and go as far as you can.

*During open lab periods:*

- Complete the experiment.
- Analyze some data in the lab. It often happens you need something you forgot to measure.
PRE-LAB PROBLEMS

The write-up for each experiment includes problems to help you design your experiment and learn the theory. The problems are due in the lab before you begin work on the experiment. It is essential that you do the pre-lab problems and read the write-up before your lab section. Otherwise you will not be able to make good use of your time in the lab, which is your main opportunity to get help from your instructor. We recommend that you solve the pre-lab problems in your lab notebook and then hand in a photocopy. This way you will have your calculations available while you work on the experiment. You will work with a partner in the lab, but you should do the pre-lab problems independently. Solutions to the pre-lab problems will be posted after all lab sections have met.

LAB REPORTS

Your reports should give a brief and clear account of what you observed in the lab, and what conclusions you can draw from your measurements. The report should be of a quality and style comparable to what you might imagine sending to a supervisor or project coworkers if you were working in a lab in a local high-tech company. A typical report will be three to six pages long. It will contain an introduction which describes the experiment in a few sentences, one or more figures depicting the circuit or other apparatus, a summary of the data or other observations, analysis of the data, and conclusions. It should be self-contained in that one should not have to be a student or instructor in this course to understand it. If the overall goal of an experiment is to measure some quantity, then an account of the important random and systematic errors will be necessary. Always strive to make simple best estimates of errors, to avoid wasting time estimating errors that will not contribute to the final result, and to avoid elaborate propagation-of-errors calculations unless they are really necessary.

Data plots are one aspect of the lab report that merits special attention. Each plot should be of a size and quality to enable a clear understanding of the data, and provided with appropriate axis labels and units. Before you take data on a particular circuit’s characteristics, think about what data you should take to make an informative plot. For example, if you are measuring characteristics of a low-pass filter, it has an expected “roll off” frequency that you can calculate, or find experimentally. The characteristics of a low-pass filter are best illustrated using a logarithmic scale, so choose your x-axis as logarithmic with the roll-off frequency near the center of the x-axis scale. When you take the data in the lab, and depending on the complexity of the data, 10-30 measurements is usually sufficient for a meaningful plot. Choose data points to cover the range uniformly on the log plot. Then go back and take more data where something “interesting” is happening in the circuit characteristics.

INTRODUCTION
PROJECTS

The last three weeks of the semester are devoted to projects. You will use the skills you have learned to explore a topic of your choice. A few weeks before the projects start, a list of suggested experiments and some example reports from previous years will be available. If you have an idea for a project at any time during the semester, by all means discuss it with your instructor and begin reading and collecting the materials you will need.

TEXTBOOK

The main textbook for the course is Diefenderfer and Holton, *Principles of Electronic Instrumentation*, 3rd ed. Saunders College Publishing (1994). This appears to be a very readable and helpful text, and is the first year we will be using it for this course. In previous years this class has used Horowitz and Hill, *The Art of Electronics*, 2nd Ed., Cambridge University Press (1989). H&H is very complete and practical and is the most used electronics reference text among physicists. However, it’s size and level of detail make it more useful as a reference that as a textbook. A number of copies are on reserve in the lab and in the library. It is recommended that you take advantage of these copies. There are also a few references in the manual to D.V. Bugg, *Electronics: Circuits, Amplifiers, and Gates*, Adam Hilger (1991). This text is available in the lab and on reserve in the library.

LAB NOTEBOOKS

Whenever you work in a laboratory it is essential to keep a record of your experiments in a bound lab notebook. The purpose of your lab book is to document your experiment clearly and accurately. The usual guideline is that you record enough so that you could reproduce the experiment without too much difficulty a year later. It often happens that a result must be reproduced in the light of new information or criticism.

Your lab book will not be graded directly. Your instructor may want to see the original data in your lab book when trying to help you diagnose problems. If you are reading instruments while your partner is writing down the data, it is all right to make a photocopy of the data immediately after you leave the lab and paste or staple it permanently in your own book.

The notebook must be bound, not loose-leaf, and it should contain graph paper, rather than lined writing paper. If you ever forget to bring your notebook to the lab and use loose sheets instead, be sure to staple these into your lab book as soon as possible. Do not tuck loose sheets into the notebook. If you rely on photocopied pages from data books, pages copied from instrument
manuals, or any other loose materials, staple them into your book. Make all entries in pen, not pencil, and put a single line through errors, so the text or data can still read if you later decide it was correct after all. Enter all data, text, and calculations directly into the lab book. Do not use loose sheets!

Entries in a lab notebook do not have to be neat, but some organization is very helpful. Reserve the first few pages for a table of contents, and keep it up to date. At the beginning of each day, write down the name of your lab partner and the date and time. Use a consistent format so it is easy to find the work that was done on a give day or a given experiment.

**FINAL EXAM**

There will be a one-hour final given on Tuesday 18 November @ 1:00 pm (in G-2B47). This exam will primarily focus on the theoretical material covered in the course of the semester as well as some practical knowledge that you are expected to have gained from the lab work.

**GRADING**

The grading will be based on a maximum of 700 points. Each of the 9 regular lab reports is worth 40 points, and each of the 9 pre-lab problem sets is worth 10 points. (There are only 9 lab reports because no report is required for the first lab.) Your final project will be worth 150 points – 25 points for a project proposal, 50 points for your final project seminar, and 75 points for your final report. The one-hour final exam will be worth 100 points.

Late work will be graded at the discretion of your instructor. There will be at least a 10 point penalty per week when a report is late. No pre-lab problems will be accepted after the solutions are posted.

**LAB RULES**

If you are the last to leave the lab, first be sure to turn off all equipment, especially soldering irons and hot plates. Then close all windows, lock the door, and turn out the lights. Never prop the door open and never give the lock combination to anyone. Anyone who has authorization to use the lab should already have the combination. (If you forget the combination, ask an instructor.) The equipment is expensive and it would be very difficult to replace.

Before you leave the lab, clean up your mess. Your bench top should be totally cleared except for the oscilloscope stand, toolbox, and multimeter. Your own circuit boards and other equipment should be left on your personal labeled shelf in one of the storage cabinets. Communal equipment, including meters, stop watches, tools from the bench, cables, etc. should be returned
to their storage locations.

Faults or damage that occur to any instrument or non-trivial component should be reported to an instructor or to Michael Thomason (his phone number is posted in the lab). Label the offending item with a tag stating the nature of the fault to help us with repairs. Instruments, tools, or components that are taken out of the lab should be entered on the sign-out sheet by the door.

**DISABILITIES**

If you qualify for accommodations because of a disability, please submit to your instructor a letter from Disability Services, in a timely manner, so that your needs may be addressed. Disability Services determines accommodations based on documented disabilities (303-492-8671, Willard 322, www.colorado.edu/disabilityservices).

**OBSERVANCE OF RELIGIOUS HOLIDAYS AND ABSENCES FROM CLASSES AND/OR EXAMS**

Please inform your instructor, at least two weeks in advance, if any of the class activities, including the labs, lectures, exams, or final presentations, fall on a religious holiday that will preclude your attendance. Generally, it is straightforward to make-up for lab absences, but we should be aware of the any reasons for absence from any particular session. If you have a conflict with the exam or final presentations, please let your instructor know as soon as possible so that these activities can be rescheduled.

**HONOR CODE**

The University of Colorado at Boulder Honor Code applies to all your work in this class. In the case of a lab course, in the lab exercises you will be working with a partner, with whom you will share notes and data. However, in submitting a lab report, you are asserting that you were a full participant in doing the work presented the lab, and that the data you present were taken by you and your lab partner. For the lab reports, a written honor code pledge is not necessary, but the honor code applies nevertheless. Fabrication of data, copying of data from another group, or wholesale copying of data from your lab partner when you were not a participant in the actual construction, testing, and taking of data are all honor code violations. The exam will include the honor code pledge that you must sign. The presentation and final report must represent your work, citing other sources of material appropriately.
SAFETY IN THE LABORATORY

A laboratory should not be a dangerous place. Usually only a small amount of effort is needed to make your time in the lab as safe as the time you spend at home. Common laboratory hazards include electrical shock and fire, wet chemicals and their vapors, dry chemicals, power tools, lasers, compressed gases, vacuum, radioactivity, exposed belts and pulleys, electromagnetic radiation, and cryogenic liquids.

In this section we cover general safety precautions and electrical safety. You might be exposed to other hazards depending on the project you choose. If you feel you are exposed to a hazard that you do not fully understand, stop what you are doing and ask your instructor.

GENERAL PRECAUTIONS

Never work with any hazard that you do not understand.

Never work in a laboratory alone. This can sometimes be a very frustrating constraint.

Always wear eye protection when using power tools or handling chemicals.

Never use any chemical if you are not aware of the hazards it presents.

Never use any chemical that you do not know how to dispose of.

Keep your work area neat and uncluttered.

Keep all electrical cables off of floors and away from traffic.

Know where fire extinguishers and exits are located.

In case of any emergency, call 911, and notify an instructor if possible.

Never bring food or drinks into a laboratory.

ELECTRICAL SAFETY

Electrical equipment and circuits are a major hazard in the lab. You must read this entire section during the first week of the lab.

The chief sources of electric power in the lab are the 110 V ac power outlets in the walls, extension cords and consoles and the dc power units with up to 50 Volts between their terminals. Much higher voltages occur inside some instruments (> 14,000 V inside the oscilloscope), but these are generally not exposed. Do not stick your fingers inside an instrument when the power is on.

It is the current through your body that is dangerous. The voltage required to produce a dangerous current depends, by Ohm's law, on your body resistance. The damage it does to you depends on...
the current path through your body. The danger is much greater for a current that enters by one hand, passes through your body, and exits by the other hand, than for a current that passes between two fingers of the same hand. Therefore, keep one hand behind your back when dealing with hazardous electrical systems.

The physiological effect of different currents is as follows:

- 10 to 20 mA: painful sensation
- 20 to 40 mA: muscular paralysis, cannot let go
- 40 to 80 mA: breathing is difficult
- 100 to 200 mA: fibrillation of the heart and death
- > 200 mA: heart muscles are clamped. Recovery is possible with immediate first aid.

Be sure the power is off before touching a helpless person.

The internal resistance of your body (right hand to left hand, or hand to leg) is typically 500 Ω. In series with this is the surface resistance of your skin, which varies from 1000 Ω when moist to over 100 kΩ when dry. Thus a voltage as low as 50 V can produce a hazardous current if your hands are wet.

Never work with electrical equipment if you hands or clothing are wet. Dry yourself thoroughly before you start work. Note that when you are hot the perspiration on your hands increases the hazard.

**THE PHYSIOLOGICAL EFFECTS OF ELECTRIC SHOCK**

The figure shows the physiological effect of various current densities. Note that voltage is not a consideration. Although it takes a voltage to make the current flow, the amount of shock-current will vary, depending on the body resistance between the points of contact.

As shown in the chart, shock is relatively more severe as the current rises. At values as low as 20 mA, breathing becomes labored, finally ceasing completely even at values below 75 mA.

As the current approaches 100 mA, ventricular fibrillation of the heart occurs -- an uncoordinated twitching of the walls of the heart's ventricles.

Above 200 mA, the muscular contractions are so severe that the heart is forcibly clamped during the shock. This clamping protects the heart from going into ventricular fibrillation, and the victim's chances for survival are good.
THE FATAL CURRENT

(Reprinted through the courtesy of Fluid Controls Company, University of California, Safer Oregon)

Strange as it may seem, most fatal electric shocks happen to people who should know better. Here are some electro-medical facts that should make you think twice before taking that last chance.

IT'S THE CURRENT THAT KILLS

Offhand it would seem that a shock of 10,000 V would be more deadly than 100 V. But this is not so! Individuals have been electrocuted by appliances using ordinary house currents of 110 V and by electrical apparatus in industry using as little as 42 V direct current. The real measure of shock's intensity lies in the amount of current (amperes) forced through the body, and not the voltage. Any electrical device used on a house wiring circuit can, under certain conditions, transmit a fatal current.

While any amount of current over 10 mA is capable of producing painful to severe shock, currents between 100 and 200 mA are lethal.

Currents above 200 mA, while producing severe burns and unconsciousness, do not usually cause death if the victim is given immediate attention. Resuscitation, consisting of artificial respiration, will usually revive the victim.

From a practical viewpoint, after a person is knocked out by an electrical shock it is impossible to tell how much current passed through the vital organs of their body. Artificial respiration must be applied immediately if breathing has stopped.

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![Physiological Effects of Electrical Currents](image-url)
\textbf{DANGER -- LOW VOLTAGE!}

It is common knowledge that victims of high-voltage shock usually respond to artificial respiration more readily than the victims of low-voltage shock. The reason may be the merciful clamping of the heart, owing to the high current densities associated with high voltages. However, lest these details be misinterpreted, the only reasonable conclusion that can be drawn is that 75 V are just as lethal as 750 V.

The actual resistance of the body varies depending upon the points of contact and the skin condition (moist or dry). Between the ears, for example, the internal resistance (less than skin resistance) is only 100 $\Omega$, while from hand to foot it is closer to 500 $\Omega$. The skin resistance may vary from 1000 $\Omega$ for wet skin to over 500,000 $\Omega$ for dry skin.

When working around electrical equipment, move slowly. Make sure your feet are firmly placed for good balance. Don't lunge after falling tools. Kill all power, and ground all high-voltage points before touching wiring. Make sure that power cannot be accidentally restored. Do not work on ungrounded equipment.

Don't examine live equipment when mentally or physically fatigued. Keep one hand in pocket while investigating live electrical equipment.

Above all, do not touch electrical equipment while standing on metal floors, damp concrete or other well grounded surfaces. Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.

Do not work alone! Remember the more you know about electrical equipment, the more heedless you're apt to become. Don't take unnecessary risks.

\textbf{WHAT TO DO FOR VICTIMS}

Cut voltage and/or remove victim from contact as quickly as possible -- but without endangering your own safety. Use a length of dry wood, rope, blanket, etc., to pry or pull the victim loose. Don't waste valuable time looking for the power switch. The resistance of the victim's contact decreases with time. The fatal 100 to 200 mA level may be reached if action is delayed.

If the victim is unconscious and has stopped breathing, start artificial respiration at once. Do not stop resuscitation until medical authority pronounces the victim beyond help. It may take as long as eight hours to revive the patient. There may be no pulse and a condition similar to rigor mortis may be present; however these are the manifestations of shock and are not an indication the victim has succumbed.
SELECTED REFERENCES

EXPERIMENTAL METHODS
Building Scientific Apparatus - Moore, Davis & Coplan, 2nd ed. (Addison-Wesley).
Modern Physical Laboratory Practice - Strong (Prentice-Hall 1938).
Data Reduction & Error Analysis in the Physical Sciences - Bevington.
Vacuum Technology - Roth, 2nd revised ed. (North-Holland).

ELECTRONICS
Principles of Electronic Instrumentation – Diefenderfer and Holton
The Art of Electronics - Horowitz and Hill
Electronics: Circuits, Amplifiers, and Gates - D.V. Bugg

DATA TABLES
Handbook of Chemistry and Physics (CRC).
Handbook of Physics - Gray (American Inst. of Phys.).
Tables of Physical & Chemical Constants - Kaye & Laby (14th Ed.).
International Critical Tables (This very comprehensive set of data is in the library).

EQUIPMENT AT EACH WORK STATION

INSTRUMENT RACK:
1 each Oscilloscope, 100 MHz, 4 channel digital. Tektronix TDS 3014B
1 each Power Bin for plug-in units. Tek. TM504
1 each Counter-Timer, to 100 MHz. Tek. DC504A
1 each Function Generator 15 Mhz. Agilent 33120A
1 each Dual dc power supply 30V 2 A, 5 Volts. Tektronix PS280

IN WOOD TOOL-BOX ON BENCH
1 each Digital Multimeter - Fluke model 77 (0.2% to ±1%)
1 pair needle nose pliers
1 pair wirecutter/stripper
1 each small screwdriver
2 each BNC coaxial L connector
5 each BNC coaxial T connector
1 each BNC coaxial 50 Ω terminator