

IETTI-105 – AC Circuit Projects (Semester 2 PROJECTS)

NAME: _____

Last update 5 January 2024

Duration	Project	Score
All semester	Career preparation	
First 6 weeks	Development Board accessory circuit	
Last 9 weeks	EET lab subsystem (solid-state devices)	

Essential information about this course:

- Learning to independently manage projects and solve all the problems encountered in a project from conception to completion is even more important than learning how circuits work. You must budget your time and resources effectively to complete projects on time and to specification. Careful planning at the start of every project is key to success. Your instructor will offer advice on project selection and scope, and you will be responsible at the end for meeting the planned objectives.
- This is a laboratory course, but *the projects are not pre-designed*. You will manage each project just like real projects within your career.
- Your course grade is a simple average of all project grades, in turn based on timely and correct completion of all “deliverables”. As usual, clarifying questions are welcome, but all results presented to the instructor will be assessed just like answers submitted on an exam.
- You should budget a minimum of 12 hours per week for this course, approximately 8 hours in-class and 4 hours out-of-class. The lab is yours to use during all open-school hours. *Do not let the lack of fixed hours for this course lead to procrastination – manage your time wisely!*
- Successful students (1) review relevant theory before planning projects, (2) prioritize hands-on lab time, (3) set reasonable project goals, and (4) document data neatly and accurately.

Values

This educational program exists for one purpose: to empower you with a comprehensive set of knowledge, skills, and habits to unlock opportunities in your chosen profession. The following values articulate personal attitudes guaranteed to fulfill this purpose, and the principles upon which this program is designed. They embody what I like to call a *strong learning ethic*, similar to a strong work ethic but applied to the learning process rather than a job.

Ownership – you are the sole proprietor of your education, of your career, and to a great extent your quality of life. No one can force you to learn, make you have a great career, or grant you a fulfilling life – these accomplishments are possible only when you accept responsibility for them.

Responsibility – *ensuring* the desired outcome, not just *attempting* to achieve the outcome. Responsibility is how we secure rights and privileges.

Initiative – independently recognizing needs and taking responsibility to meet them.

Integrity – living in a consistently principled manner, communicating clearly and honestly, applying your best effort, and never trying to advance at the expense of others. Integrity is the key to trust, and trust is the glue that binds all relationships personal, professional, and societal.

Perspective – prioritizing your attention and actions to the things we will all care about for years to come. Never letting short-term concerns eclipse the long-term.

Humility – no one is perfect, and there is always something new to learn. Making mistakes is a symptom of living, and for this reason we need to be gracious to ourselves and to others.

Safety – assessing hazards and avoiding unnecessary risk to yourself and to others.

Competence – your ability to consistently and independently apply knowledge and skill to the solution of practical problems. Competence includes the ability to verify the appropriateness of your solutions and the ability to communicate so that others understand how and why your solutions work.

Diligence – exercising self-discipline and persistence in learning, accepting the fact there is no easy way to absorb complex knowledge, master new skills, or overcome limiting habits. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all documentation complete, and all root-causes of problems identified and corrected.

Community – your actions impact other peoples' lives, for good or for ill. Conduct yourself not just for your own interests, but also for the best interests of those whose lives you affect.

Respect is the acknowledgment of others' intrinsic capabilities, responsibilities, and worth. Everyone has something valuable to contribute, and everyone deserves to fully *own* their lives.

EET Program Learning Outcomes

- (1) **COMMUNICATION and TEAMWORK** – Accurately communicate ideas across a variety of media (oral, written, graphical) to both technical and non-technical audiences; Function effectively as a member of a technical team.
- (2) **SELF-MANAGEMENT** – Arrive on time and prepared; Work diligently until the job is done; Budget resources appropriately to achieve objectives.
- (3) **SAFE WORK HABITS** – Comply with relevant national, state, local, and college safety regulations when designing, prototyping, building, and testing systems.
- (4) **ANALYSIS and DIAGNOSIS** – Select and apply appropriate principles and techniques for both qualitative and quantitative circuit analysis; Devise and execute appropriate tests to evaluate electronic system performance; Identify root causes of electronic system malfunctions.
- (5) **PROBLEM-SOLVING** – Devise and implement solutions for technical problems appropriate to the discipline.
- (6) **DOCUMENTATION** – Interpret and create technical documents (e.g. electronic schematic diagrams, block diagrams, graphs, reports) relevant to the discipline.
- (7) **INDEPENDENT LEARNING** – Select and research information sources to learn new principles, technologies, and/or techniques.

Course description

This course reinforces the content of IETTT-104 (AC Circuit Theory) through multiple student-designed projects, each project's scope and functional criteria defined by the instructor with input from the student. This course also prepares the student for entry into the profession through résumé and cover letter writing as well as job research. All students must present their job research findings at the Technical Advisory Committee (TAC) meeting held with industry advisors. Additionally, students take a comprehensive exam covering all theory course topics to date.

Course learning outcomes

- Update résumé and cover letter. (Addresses Program Learning Outcome 6)
- Set and meet deadlines for the timely completion of all project phases. (Addresses Program Learning Outcomes 1, 2)
- Test and modify prototype designs based on principles of discrete semiconductor components, researching appropriate information sources as necessary to assist in the design process. (Addresses Program Learning Outcomes 3, 4, 5, 7)
- Devise and safely implement conformance (type) tests based on criteria defined by the instructor and established technical standards, including but not limited to electrical safety (e.g. NFPA 79 Protective Bonding). (Addresses Program Learning Outcomes 3, 4, 6)
- Devise and safely implement functional tests based on practical project criteria defined by the instructor and/or external clients. (Addresses Program Learning Outcomes 3, 4, 6)
- Document all project work in written form including test results, schematic diagrams, and summary of accomplishments. (Addresses Program Learning Outcomes 1, 6)
- Demonstrate knowledge of Theory topics from IETTT-101 and IETTT-104 by taking a comprehensive written exam. (Addresses Program Learning Outcomes 4, 5)
- Take the ESA-1 exam offered by the ISCET and required by the State of Idaho for this program. (Addresses Program Learning Outcomes 4, 5)

Required Tools, Supplies, and Software

Listed by IETTI course number and course type (**Thy** = theory, **Exp** = Experiments, **Prj** = Projects).

Semester 1 = IETTI-101 (Theory), 103 (Experiments), and 102 (Projects)

Semester 2 = IETTI-104 (Theory), 112 (Experiments), and 105 (Projects)

Semester 3 = IETTI-222 (Theory), 221 (Experiments), and 220 (Projects)

Semester 4 = IETTI-223 (Theory), 225 (Experiments), and 236 (Projects)

Tool, Supply, or Software installation	Thy 101	Exp 103	Prj 102	Thy 104	Exp 112	Prj 105	Thy 222	Exp 221	Prj 220	Thy 223	Exp 225	Prj 236
\$25 scientific calculator	X	X	X	X	X	X	X	X	X	X	X	X
\$300 personal computer	X	X	X	X	X	X	X	X	X	X	X	X
\$10 USB “flash” drive	X	X	X	X	X	X	X	X	X	X	X	X
\$50-\$400 digital multimeter		X	X		X	X		X	X		X	X
\$150 USB-based oscilloscope		X	X		X	X		X	X		X	X
\$10 solderless breadboard (e.g. Busboard BB830)		X	X		X	X		X	X		X	X
\$25 grounding wrist strap		X	X		X	X		X	X		X	X
\$10 slotted screwdrivers (1/8”,1/4”)		X	X		X	X		X	X		X	X
\$10 Phillips screwdrivers (#1,#2)		X	X		X	X		X	X		X	X
\$10 jeweler’s screwdriver set		X	X		X	X		X	X		X	X
\$10 wire strippers, 18-24 AWG		X	X		X	X		X	X		X	X
\$10 needle-nose pliers		X	X		X	X		X	X		X	X
\$20 diagonal wire cutters		X	X		X	X		X	X		X	X
\$10 metal rule (inches & mm)		X	X		X	X		X	X		X	X
\$10 alligator-clip jumper wires (package of at least ten)		X	X		X	X		X	X		X	X
\$15 batteries: 6 Volt and 9 Volt		X	X		X	X		X	X		X	X
\$15 illuminated jeweler’s loupe		X	X		X	X		X	X		X	X
\$10 safety glasses			X		X	X			X			X
\$25-\$100 soldering iron (pencil-tip), 30 Watts or less			X		X	X			X			X
\$15 tube/spool of rosin-core solder			X		X	X			X			X
\$90 PLC I/O card		X			X			X			X	
\$15 microcontroller and software								X			X	X
\$0 software: Python interpreter	X			X			X			X	X	X
\$0 software: schematic editor		X	X		X	X		X	X		X	X
\$0 software: Notepad++ text editor		X			X			X			X	
\$0 software: NGSPICE circuit sim.		X			X			X			X	
\$0 software: WSL		X			X			X			X	
\$0 software: tshoot fault sim.		X			X			X			X	
\$0 software: PCB layout editor											X	X
\$0 software: packet-sniffing software										X	X	X
\$0 archive: EETREF collection	X			X			X			X		

Required Tools, Supplies, and Software

Scientific calculator – at minimum your calculator must perform trigonometric functions (sine, cosine, tangent, etc.), offer multiple memory registers, and display values in both scientific and “engineering” notations. I recommend either the Texas Instruments model TI-36X Pro or the Casio model fx-115ES because they easily perform complex-number arithmetic necessary for AC circuit analysis and are inexpensive.

Personal computer – all course materials are available in electronic format and are free (most are also open-source), making a portable computer extremely useful. The school provides personal computers for on-campus use, but having your own will enable you to work outside of school. Most operating systems, size of hard drive, amount of RAM memory, and screen size is appropriate, but your computer must have a keyboard and mouse (i.e. no tablets). Avoid ChromeBooks. Useful features worth higher cost include an RJ-45 Ethernet port and an EIA/TIA-232 (9-pin) serial port.

Multimeter – this is your first and most important electronic test instrument. At minimum it must measure DC and AC voltage, DC and AC current (milliAmpere range), resistance, and “diode check” voltage drop. Useful features worth higher cost include microAmpere current measurement, true-RMS AC measurement (for second-semester courses and above), frequency measurement, capacitance measurement, and minimum/maximum value capture. Cost is a strong function of accuracy, frequency range, and safety (“Category” ratings for over-voltage exposure). The Fluke model 87-V is an excellent professional-grade choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. Note that Fluke offers a 25% educational discount for students.

Oscilloscope – once too expensive for student purchase, entry-level USB-based oscilloscopes now cost less than a textbook. Pico Technology is an excellent brand, and their model 2204A comes with high-quality probes as well. Plugged into your personal computer using a USB cable, the Picoscope turns your computer’s monitor into a high-resolution oscilloscope display. Features include two measurement channels, 10 MHz bandwidth, built-in arbitrary waveform generator (AWG), ± 100 Volt over-voltage protection, digital “cursors” for precise interpretation of amplitude and frequency, meter-style measurement capability, Fast Fourier Transform algorithm for frequency-domain measurement, export ability to several graphic image formats as well as comma-separated variable (.csv) files, and serial communications signal decoding. Together with your multimeter, solderless breadboard and Development Board (which you will construct in the IETTL-102 Project course and is yours to keep) this forms a complete electronics laboratory for doing experiments and projects outside of school.

Soldering – the equipment you purchase for soldering need not be expensive, *if* you purchase the right solder. For electronics work you *must* use rosin-core solder. Kester is an excellent brand, and you should avoid cheap imported solders. For lead-based solder, a 63% tin and 37% lead alloy (Sn63/Pb37) works very well. A one-pound roll is likely more solder than you will need in these courses, so I recommend buying just a small tube or small roll. I recommend a fine-tipped soldering iron (15 Watts continuous power, although some with adjustable temperature controls may have higher power ratings to get up to soldering temperature more quickly) and a solder diameter 0.031 inches or smaller for doing fine printed-circuit board work. Also, keep the tip of your soldering iron clean by wiping it against a damp sponge or paper towel when hot, and not leaving it hot any longer than necessary. Hakko, X-tronic, and Lonove are all recommended brands.

PLC I/O card – any DC combo input-output card designed for use with Automation Direct Koyo “CLICK” PLC processors, such as the model C0-16CDD1 or C0-16CDD2 eight-point DC I/O cards.

Microcontroller – these courses are not brand- or model-specific, but the Texas Instruments MSP430 series is highly recommended for their powerful features, modern design, and programmability in multiple languages (assembly, C, C++, and Sketch). I particularly recommend the model MSP-EXP430G2ET “LaunchPad” development board (MSP430G2553IN20 microcontroller chip) with Code Composer Studio for the IDE software. A hobbyist-grade microcontroller such as the popular Arduino and Parallax BASIC Stamp are permissible only in first-year courses, but not in second-year courses.

Required Tools, Supplies, and Software

All software and documentation required for these courses is free, and much of it is open-source.

Python interpreter – available from `python.org` as a free download, Python is an interpreted programming language that works exceptionally as a scientific calculator. When installing, be sure to enable “Add python.exe to PATH” option.

Schematic editor – this is used to draft schematic diagrams for circuits. KiCad offers an excellent schematic editor as well as other tools useful for creating printed circuit board (PCB) layouts.

Text editor – this is used to create plain-text files, kind of like a word processor but lacking formatting features such as typeface, font size, etc. **Notepad++** is a very good editor, but others work well too.

NGSPICE – this is a modern adaptation of the venerable SPICE circuit simulator which uses a text-coded “netlist” rather than a visual schematic diagram to describe circuits. The installer lacks sophistication, being nothing more than a compressed (zip) file that you unpack. Once installed, you should instruct your computer’s operating system to automatically associate any files ending in the extension `.cir` with the NGSPICE executable file `ngspice.exe` so that all of your netlist files will appear with the NGSPICE icon and will automatically load into NGSPICE when double-clicked.

WSL – Windows Subsystem for Linux is a “virtual machine” Linux operating system that runs within the Windows operating system, giving you a command-line user environment mimicking that of a Unix operating system. It is a free application from Microsoft, with instructions available from Microsoft on how to install. I recommend installing the “Debian” distribution of WSL. Once installed, you will issue these commands in the following order to install all the necessary programming tools:

- `sudo apt update`
- `sudo apt install build-essential`

tshoot – this is a specialized circuit-simulator program that inserts faults into circuits and tests your ability to locate them. The download consists of a single “tar” archive file which you must unpack and compile using the following two commands within a Unix-type operating system or within WSL. The fourth command listed below starts and runs the application:

- `mkdir tshoot ; mv -v *.tar tshoot ; cd tshoot`
- `tar xvf *.tar`
- `make`
- `./tshoot`

EETREF document collection – an archive of manufacturer datasheets, manuals, tutorials, application notes, whitepapers, regulatory standards, and other documents in electronic form stored on every computer in the lab, in a folder marked “EETREF”. Copy this collection to your own computer for future reference.

PCB layout editor – this is specialized drafting software intended for creating graphic files to be sent to printed circuit board (PCB) manufacturers so you can order your own custom PCBs. Again, KiCad is highly recommended.

Packet-sniffing software – this is specialized software for monitoring network communications. An excellent (and free) option is **Wireshark**.

IDE software – an “Integrated Development Environment” is a software package used to write code, and for our purposes this would be code meant to run on a microcontroller. For the Texas Instruments MSP430 we use **Code Composer Studio** as it supports assembly language, C, and C++. A third-party add-on called **Energia** supports Sketch programming, identical to that used by the popular Arduino microcontroller.

file eet_tools

Grading standards for Project courses

Your grade for this course is based on the simple average of all project scores (rounded *down* to a whole-number value). Each individual project score originates from the rubric included within each listed project.

This course is based on project design, testing, and construction, and does not have fixed start and stop times as is the case with instructor-facilitated theory sessions. However, your punctual and consistent attendance is important for your success, as these activities require significant time-on-task to complete. Any off-campus project work must be arranged with the instructor and teammates.

If you must be late or absent, it is imperative that you contact your instructor and all teammates so plans may be adjusted. It is still your responsibility to meet all deadlines.

A failing (F) grade will be earned for the entire course if any project is not completed on or before the deadline date, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another's work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

Getting help in the lab

Success in this career is largely a function of your ability to *independently* solve complex problems and to *empirically* learn new concepts and techniques. You will find the design, construction, testing, and diagnosis of real circuits and systems catalyze these abilities. During this course you may at times find yourself faced with a seemingly unsolvable problem. Your instructor's job is to provide practical advice useful for solving these problems, without directly solving them for you. Although this may feel frustrating for your instructor to withhold a solution from you, know that letting others solve these problems for you actually hinders your own professional development and limits your career opportunities.

Any time you request help, your instructor will first check to see you have done the following:

- **Simplify** – make problems manageable by building and testing your system in stages, by dividing large systems into smaller sections to isolate problems, and by avoiding complexity that isn't absolutely necessary to the function you are trying to obtain at that time. A common mistake is to build large systems without testing along the way in an attempt to save time, but this strategy almost never works!
- **Document** – draw a diagram before building any system, and use this to guide your analysis and design decisions. Also, have any other relevant documents available for reference, such as datasheets, tutorials, etc. A common mistake is to build systems without first building up this documentation, again in a futile effort to save time.
- **Measure and record** – take measurements using appropriate test equipment, because these measurements will reveal what your senses alone cannot perceive. Record those test results so you will not have to rely on memory to recall what you did.
- **Foundational Concepts** – always apply Foundational Concepts such as the guaranteed effects of opens and shorts, Ohm's Law, Joule's Law, Conservation of Energy and of Electric Charge, Kirchhoff's Laws, properties of series and of parallel networks, etc. when solving problems. Reference a list of these if necessary, checking them one by one to prompt and guide your reasoning.

A good way to remember these is to use the phrase, "*Slow Down My Friend!*" (Simplify, Document, Measure/record, and Foundational Concepts) which is also a reminder that problem-solving requires patience. A great many student problems are caused by impatience and an urge to take shortcuts!

A final suggestion to help you complete experiment and project assignments is to consult the Case Tutorial, Tutorial, and Questions chapters of the learning modules referenced your Theory course sessions for circuit ideas. If you find yourself unsure of where to begin for assigned experiments and/or projects, these references are almost always sure to help because they directly relate to the foundational concepts and principles taught in this program. Be sure to consult these references *before* requesting help from your instructor and/or classmates.

PROJECT: Career Preparation

This aim of this project is to give you perspective on the career field and also prepare you for job applications and interviewing. No previous submissions will be granted credit. For singular documents such as a résumé, your submission must be an improvement over all previous versions. Any instance of plagiarism will result in a failing grade for the entire course.

Credit for each “deliverable” is all-or-nothing. It is recommended you submit these well ahead of the deadline in order to give your instructor time to review as well as give yourself time to correct any errors. No penalty is levied for errors, but the grade for each is final by the deadline date.

Source text – <i>Career Guide</i> learning module
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URL – http://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf
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Project Deliverables include the following:

- **Written summary of attributes sought by employers** as gleaned from *multiple* advertised descriptions of electronics or related-skill technician jobs, including knowledge, skills, credentials, professional habits, and values. Job descriptions are easily found at job-search websites (e.g. indeed.com) as well as from the “Careers” pages of employer websites. The sampled job descriptions must come from more than one employer, and must be included in their entirety as source material with your submitted summary, to be presented as a collection of digital documents to this semester’s Technical Advisory Committee (TAC) meeting as useful guidance for program faculty. The employers sampled for your knowledge/skill/habit summary must *not* be personally represented at the upcoming TAC meeting.
- **Participation in Technical Advisory Committee (TAC) meeting** held once per semester. This committee brings industry representatives together with faculty and students to offer advice on how to best run the program. Your task in this meeting is to present your findings on attributes sought by employers of electronics technicians, to give the meeting broader perspective. You should expect to be asked questions by the employer representatives as well, regarding your choice of careers, projects you are working on, etc.
- Update your **résumé** and optimize it for a current electronics technician job description, including a copy of this job description for reference.
- Write a **cover letter** directed to the appropriate individual for the same job description used to optimize your résumé.
- Take a **Comprehensive practice exam**, covering topics from IETTI-101 and IETTI-104 theory courses. Answers are given on this practice version so you can grade your own work and share with the instructor where your strong and weak areas are.
- Take a graded **Comprehensive exam** with the score counting for half of this project grade.

Semester calendar URL – <http://ibiblio.org/kuphaldt/socratic/model/calendar.html>

Instructor certifies each deliverable's completion by the prescribed deadline for credit. Note: "TAC" means the *Technical Advisory Committee* for the Electronics Engineering Technology program.

Deliverables	Deadline (by 4:00 PM)
<input type="radio"/> Explain how project is graded and identify deadline dates <input type="radio"/> Submit an official electronics technician job description <input type="radio"/> Submit another official electronics technician job description <input type="radio"/> <i>Neither</i> job description from an employer on our TAC	Day 8 of semester (–5% per day if late)
<input type="radio"/> Submit written summary of attributes sought by multiple employers <input type="radio"/> Attach all job descriptions informing your summary <input checked="" type="radio"/> Employer(s) <i>not</i> represented on our TAC	Day 15 of semester (–5% per day if late)
<input type="radio"/> Submit rough draft of résumé in PDF format <input type="radio"/> Submit rough draft of cover letter in PDF format <input type="radio"/> Attach job description targeted by résumé and cover letter	Day 30 of semester (–5% per day if late)
<input type="radio"/> Submit cover letter in PDF format with no errors <input type="radio"/> Attach job description targeted by letter	Day 50 of semester (–5% per day if late)
<input type="radio"/> Submit résumé in PDF format with no errors <input type="radio"/> Attach job description targeted by résumé	Day 60 of semester (–5% per day if late)
<input type="radio"/> Share self-graded practice Comprehensive exam results <input checked="" type="radio"/> <i>Download from Modular Electronics Learning Project site</i>	Day 65 of semester (worth 40%)
<input type="radio"/> Present written summary of attributes sought by employers to all participants at the TAC meeting	TAC meeting day (worth 10%)
<input type="radio"/> Graded Comprehensive exam score <input checked="" type="radio"/> (different version than the practice exam, score recorded)	Last day of semester (worth 50%)

PROJECT: Career Preparation

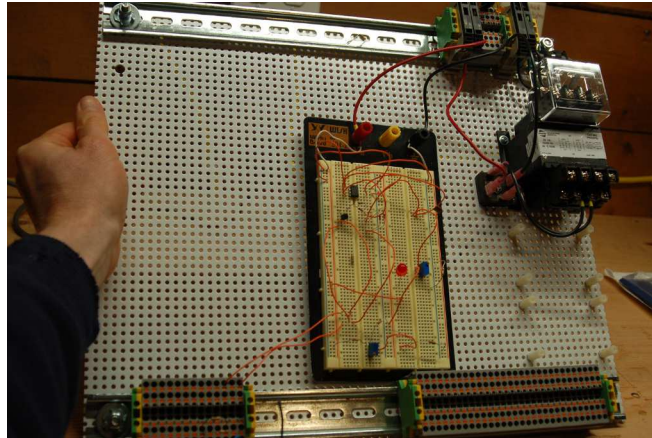
TAC committee employer list

Note: your sampled job descriptions must exclude all employers on the following list, because these employers already participate on our Technical Advisory Committee (TAC) and as such you will already be receiving direct advice from them:

- Avista Utilities
- Clearwater Paper
- Fisher Systems
- Idaho Forest Group
- Micron
- On Semi
- POWER Engineers, Inc.
- Raute-Metriguard
- Schweitzer Engineering Laboratories (SEL)
- Tri-State Memorial Hospital
- Washington Alarm

PROJECT: Development Board accessory circuit

For this project it is recommended you design, prototype, test, construct, and document a PCB-mounted accessory circuit for your *Development Board*. Other applications are possible so long as the project relates closely enough to the topics in the corresponding Theory and Experiments courses (IETTI-104 and 112, respectively). An example photograph of a typical Development Board is shown here:



Note the nylon *standoffs* threaded into perforations of this Board, tapped with 6-32 machine screw threads. These standoffs are ready to accept *printed circuit boards* (PCBs), which will be the format of circuit construction used in this project. Any project chosen must meet with the instructor's approval for relevance and complexity. This will be an *individual* project. Pre-engineered kits are not allowed unless you make substantial modifications to the design.

- Linear voltage regulator – use a three-terminal voltage regulator IC to regulator the DC voltage output by your Development Board's power supply. Use a potentiometer to control the regulator, or use a fixed regulator and a potentiometer for unregulated adjustable voltage.
 - Functional tests should include linear adjustability of voltage using a potentiometer.
 - Conformance tests should include voltage regulation within 5% of unloaded voltage while powering a load at 50% regulator IC current capacity, verification that regulator IC temperature does not exceed manufacturer-specified limits.
- Oscillator – a circuit generating audio-frequency AC signals from the Board's DC power supply.
 - Functional tests should include continuous adjustment of frequency using a potentiometer.
 - Compliance tests should include frequency-domain measurement of output signal to verify harmonics are within expected ranges for the wave-shape (e.g. square, triangle, sine).
- Electronic fuse – a circuit automatically disconnecting the DC power supply from a load if excessive current is detected.
 - Functional tests should include continuous adjustment of overcurrent trip setting using a potentiometer, and resetting using a momentary-contact pushbutton.
 - Compliance tests should trip time measurement, that current is interrupted within 20 milliseconds of a detected overcurrent condition.
- Oscilloscope – inexpensive microcontroller-based oscilloscope kits may be purchased for small fees at places like Amazon, and by adding on simple power supply and signal-limiting circuitry these may be turned into robust tools for your Development Board.
 - Conformance tests include over-voltage protection for oscilloscope kit input(s) and power conditioning for the oscilloscope

- *Your idea here*

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PROJECT: Development Board accessory circuit **NAME:** _____

Semester calendar URL – <http://ibiblio.org/kuphaldt/socratic/model/calendar.html>

On the first All-Lab day for this project, your instructor will work with you to identify reasonable test criteria for your chosen project as well as reasonable deliverables for each and every All-Lab day until the project's conclusion, making sure you have a copy of this schedule for your own records. Note that all Conformance and Functional test results must either be directly witnessed by the instructor or video-recorded, and that deliverables and their deadlines may be edited only with the instructor's consent to accommodate unforeseen circumstances.

Deliverables	Deadline (by 4:00 PM)
<ul style="list-style-type: none"><input type="radio"/> Select project<input type="radio"/> Explain how project is graded and estimate time required<input type="radio"/> Identify Conformance criteria (e.g. safety, reliability) (refer to "Construction Standards" pages)<input type="radio"/> Identify Functional criteria (e.g. features)<input type="radio"/> Submit prototype design (e.g. rough-draft schematic)<input type="radio"/> Identify deliverables for each All-Lab day<input type="radio"/> Locate/order components, materials, and other supplies<input type="radio"/> [Team project only] Write, sign, and submit Team Contract	All-lab day 1 (–5% per day if late)
<ul style="list-style-type: none"><input type="radio"/> All-Lab day 2 deliverables; submit today's Project Journal entry	(–5% per day if late)
<ul style="list-style-type: none"><input type="radio"/> All-Lab day 3 deliverables; submit today's Project Journal entry	(–5% per day if late)
<ul style="list-style-type: none"><input type="radio"/> All-Lab day 4 deliverables; submit today's Project Journal entry	(–5% per day if late)
<ul style="list-style-type: none"><input type="radio"/> All-Lab day 5 deliverables; submit today's Project Journal entry	(–5% per day if late)
<ul style="list-style-type: none"><input type="radio"/> All remaining deliverables<input type="radio"/> Submit completed Project Journal containing <i>all</i> project data<input type="radio"/> Schematic diagram challenge (–5% per re-work)<input type="radio"/> Additional objectives (see "Project Grading" page)	All-Lab day 6 (–5% per day if late)

Project grading

The standard for projects is mastery of skill and technique, and you will be given ample time to practice until everything is correct. You are also free to ask questions at any time if you need help, but know that the instructor's responsibility is to offer advice rather than solve problems for you. In this career your value is a function of your ability to solve complex problems on your own, and the *only* way to build this skill is by solving simpler problems on your own!

When you submit your finished work to the instructor the expectation is that you have thoroughly checked and double-checked it all for correctness. A "re-work" is where submitted work that is not correctly done results in a penalty, then you must re-do that work and submit again for re-inspection. Missed deadlines will result in a -5% penalty per school day. If working as a team, these penalties apply equally to all team members. Your over-all project score will be capped at a maximum value of 50% if the project is not fully functional by the final due date unless delayed by accidental component failure, in which case the penalty will merely be -5% per school day.

You should maintain *all* project records in a single document called a *Project Journal*, ideally an electronic document that is easily shared and archived. This journal must contain dated entries describing the work you did every All-Lab day, as well as schematic diagrams, code listings, data collected during experimentation, Conformance and Functional test results, list of project-specific deliverables and deadlines, etc. Journals are important for recalling precisely what you did and what is left to do, especially when there may be several days of gap between project work. Screenshots, photographs, and even videorecordings may be included in your journal as appropriate to supplement your own written notes and diagrams.

The "schematic diagram challenge" deserves elaboration here. Sketching a complete and accurate schematic diagram is vitally important for every system you design and build, but it takes too long for the instructor to perform a wire-by-wire inspection of every student's diagram on every system built. Instead, the instructor tests the accuracy of your schematic diagram by selecting random portions of your system and having you predict and measure signals there. These could be individual components or test points, they could be assuming normal operation or some special condition (e.g. a simulated fault), they could be selected from the physical system with you having to reference the schematic diagram, or vice-versa. In all cases, you must show an accurate correspondence between what you have built and what you have drawn, and demonstrate a thorough understanding of your system's behavior. Preparation consists of thoroughly reviewing both your system and your diagram, predicting what kinds of signals you ought to measure at all points in your system and making absolutely sure your schematic diagram is complete and accurate.

Correctly completing all deliverables by their respective deadlines contributes 75% to your over-all project score. Additional points are available for completing the following by the last All-lab due date listed in the Deliverables table:

- ☐ **+5%** – Final documentation created on computer, not hand-written (including schematic diagrams).
- ☐ **+5%** – Write an "Abstract" explaining to a non-expert in very simple, non-technical terms what the project is supposed to do.
- ☐ **+5%** – *Bill of Materials* complete with part numbers, manufacturers, and current list prices for *all* components (including recycled components), plus a total cost for the project.
- ☐ **+5%** – Produce a "User's Guide" explaining to a non-expert how to operate the project. This may take the form of a written document or an instructional video.
- ☐ **+5%** – Impeccable craftsmanship, comparable to that of a professional assembly. This includes all conductors neatly routed either parallel or perpendicular to each other.

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PROJECT: EET lab subsystem

A recommended project selection is for electric power control used within the EET lab's miniature power grid, but other applications are possible so long as the project relates closely enough to the topics in the corresponding Theory and Experiments courses (IETTI-104 and 112, respectively). A campus-based system is eligible for school funding since it will remain the property of the school.

Options exist for the choice of project, with some examples listed below. Project design and construction should be staged in such a way so as to align with topics in the corresponding Theory course. This will be an *individual* project unless you choose your own project of sufficient complexity to warrant a team effort. Any project selected must meet with the instructor's approval for relevance and complexity, and the instructor also reserves the right to assign a project if it meets a known need. Pre-engineered kits are not allowed unless you make substantial modifications to the design.

- Dump Load controller on the lab's DC power grid
 - Stage 1 = Resistive (or useful) load connected to grid through a power transistor, with manual disconnect switch, shunt resistor provided for current measurement, and fuse for overcurrent protection; Measure and record the load's current as the transistor is activated by a manual control. Functional criteria should include full saturation of power transistor when on; Conformance testing should include verifying proper action of overcurrent protection (i.e. fuse blows when it should).
 - Stage 2 = Add voltage-sensing capability, turning load on when voltage is too high and off when voltage is too low. Functional criteria should include adjustability of high/low voltage threshold values; Conformance criteria should include thermal limits of power transistor.
 - Stage 3 = Augment shunt-regulating control with automatic disconnection in the event of dump load overcurrent, enabling the station to protect itself even if the fuse fails to blow. Functional criteria should include user-adjustability of trip setting; Conformance criteria should include tripping time.
- DC-AC converter for the lab's DC power grid
 - Stage 1 = Basic DC-to-AC conversion demonstrated as a proof-of-concept. Functional criteria should include pulse-width modulation adjustability. Conformance criteria should include ensuring no semiconductor switching device experiences excessive voltage transients.
 - Stage 2 = Provide adjustable frequency control for the AC output. Functional criteria should include limits on that frequency adjustment so as to not exceed transformer's limits. Conformance criteria should include overcurrent protection on both input and output.
 - Stage 3 = Provide adjustable amplitude control for the AC output. Functional criteria should include limits on that amplitude adjustment so as to not saturate the transformer. Conformance criteria should include AC output testing over a range of expected DC input voltages.
- Visitor demonstration unit: *PWM motor speed control*
 - Stage 1 = Control of DC motor direction using a manual switch. Functional criteria should include predictable motor shaft direction with switch position; Conformance criteria should include overcurrent protection for motor.
 - Stage 2 = Use 555 timer (or similar circuit) to produce a PWM-modulated signal driving a power transistor to control motor speed. Functional criteria should include linear motor speed control by user-adjustment of a potentiometer; Conformance tests should include mitigation of inductive "kickback" to not exceed transistor ratings.
 - Stage 3 = Augment motor control with latching Forward/Stop/Reverse pushbutton action. Functional criteria should include necessity of "stopping" before reversing direction; Conformance criteria should include "fool-proof" operation if multiple buttons pressed simultaneously.
- *Your idea here*
 - Stage 1 = *applying concepts from sessions 1-36 of theory course*
 - Stage 2 = *applying concepts from sessions 37-48 of theory course*

→ Stage 3 = *applying concepts from sessions 49-60 of theory course*

Semester calendar URL – <http://ibiblio.org/kuphaldt/socratic/model/calendar.html>

On the first All-Lab day for this project, your instructor will work with you to identify reasonable test criteria for your chosen project as well as reasonable deliverables for each and every All-Lab day until the project's conclusion, making sure you have a copy of this schedule for your own records. Note that all Conformance and Functional test results must either be directly witnessed by the instructor or video-recorded, and that deliverables and their deadlines may be edited only with the instructor's consent to accommodate unforeseen circumstances.

Deliverables	Deadline (by 4:00 PM)
<input type="radio"/> Select project <input type="radio"/> Explain how project is graded and estimate time required <input type="radio"/> Identify Conformance criteria (e.g. safety, reliability) (refer to "Construction Standards" pages) <input type="radio"/> Identify Functional criteria (e.g. features) <input type="radio"/> Submit prototype design (e.g. rough-draft schematic) <input type="radio"/> Identify deliverables for each All-Lab day <input type="radio"/> Locate/order components, materials, and other supplies <input type="radio"/> [Team project only] Write, sign, and submit Team Contract	All-lab day 7 (–5% per day if late)
<input type="radio"/> All-Lab day 8 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 9 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 10 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 11 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 12 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 13 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All-Lab day 14 deliverables; submit today's Project Journal entry	(–5% per day if late)
<input type="radio"/> All remaining deliverables <input type="radio"/> Submit completed Project Journal containing <i>all</i> project data <input type="radio"/> Schematic diagram challenge (–5% per re-work) <input type="radio"/> Additional objectives (see "Project Grading" page)	All-Lab day 15 (–5% per day if late)

Project grading

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Functional and Conformance Testing

Engineering is the process of *designing to specification*. As such, every new design must begin with identifying those specifications and determining how to prove the design will meet or exceed each specification. Two different categories of tests apply to any design, *Functional Tests* and *Conformance Tests* (also known as *Compliance Tests* or *Type Tests*).

Functional Tests check whether the system fulfills its intended function(s). These tests focus on features, examples of which are listed here:

- A radio communication system’s ability to both transmit and receive certain types of information, to provide the user with relevant data on the system’s performance, etc.
- An engine’s ability to output a certain minimum amount of horsepower.
- A computer’s ability to process certain types of mathematical operations at certain minimum speeds, to execute functions unique to that design.
- A security system’s ability to identify authorized versus unauthorized personnel, to log access data.
- An electric motor’s ability to achieve an advertised energy conversion efficiency.
- A switch’s ability to open and close an electric circuit on demand.
- The display(s) and controls for an electronic system operate consistently and predictably.

Conformance Tests check whether the system complies with third-party regulations, safety standards, reliability requirements, etc.

- A radio communication system’s ability to transmit only the intended frequency(ies) and to not exceed FCC-regulated power output.
- An engine’s ability to operate while outputting no more pollutants than allowed by the EPA.
- A computer’s ability to process industry-standardized data types, to not radiate or conduct high-frequency signals that could interfere with other electronic devices.
- A security system’s reliability as measured over a specified range in time.
- An electric motor’s resistance to electrical ground faults, its ability to operate while not exceeding a maximum specified amount of acoustic noise.
- A switch’s physical dimensions agree with NEMA standards, can safely interrupt rated current, has a certain minimum dielectric strength, etc.
- The display(s) and controls for an installed system being operable by someone restricted to a wheelchair (i.e. Americans with Disabilities Act “Standards for Accessible Design”).

When selecting and designing your own project, you will be asked to generate a list of testable criteria which will become the foundation of your project’s Functional and Conformance Tests. After selecting your project concept, you will decide what it must do (Functional) and identify relevant safety, quality, reliability, and/or interference concerns (Conformance). Functional criteria are more or less arbitrary, but Conformance criteria is objectively-based.

The following pages list industry best-practice standards and recommendations with source references to external documents. If you are at a loss for Conformance criteria in your project, this is an excellent reference. A well-designed Conformance Test reliably measures its criterion, whatever that may be.

Construction Standards

The following list contains best-practice standards applicable to most electrical and electronic projects:

General layout

- All electrical components shall be located to avoid accidental exposure to liquids.
- All manual controls (e.g. buttons, handles, knobs) shall be accessible and function without undue effort.
- Fragile components (e.g. heat-sensitive semiconductors) shall be easily accessed for replacement.

Fastening

- All threaded fasteners shall be properly engaged and tightened.
- A minimum of 1-1/2 threads shall extend beyond the threaded hardware (e.g., nut), unless otherwise specified otherwise.
- All cable ties shall be trimmed off, flush with the back end of the strap head. (*NASA-STD-8739.4, NFPA 79 2007 edition (13.1.5.6)*)

Thermal considerations

- Power-handling components shall have adequate cooling capacity, usually in the form of a heat sink.
- When mounted vertically, the hottest components shall be located on top so their convected heat does not warm other components.
- Components dissipating heat in quantities of 1 Watt or greater, or in quantities sufficient to damage a PCB shall be mounted with sufficient standoff [$> 1.5 \text{ mm}$ (0.060 in)] and shall be mechanically restrained.

Power wiring

- All electrical sources greater than 24 Volts shall be guarded against accidental contact (e.g. use recessed terminals with no exposed metal).
- All electrical sources capable of generating currents exceeding conductor ampacity ratings shall be overcurrent-protected, regardless of voltage.
- Overcurrent protection shall be on the ungrounded (“hot”) conductor(s) only (*NFPA 70 2017 edition (240.15(A))*). No grounded conductor shall be overcurrent-protected or switched (*NFPA 70 2017 edition (240.22)*).
- Small power transformers shall be overcurrent-protected on their primary windings, and optionally on their secondary windings. For primary currents less than 2 Amperes, exclusive primary overcurrent protection may be as high as 300% of full-load rating, 250% if secondary overcurrent protection also included. For secondary currents less than 9 Amperes, overcurrent protection may be as high as 167% of full-load rating. (*NFPA 70 2017 edition (450.3(B))*)
- All metallic panels and electrical enclosures receiving power from the AC line shall be bonded to earth ground for safety, and this bonding verified by electrical resistance measurement. Resistance between nearest facility ground point (e.g. plug ground prong) and chassis shall be 0.1Ω or less. (*NASA-STD-4003A, NFPA 79 2007 edition (18.1)*)
- All power conductors shall be strain-relieved so that tension applied to them will not stress the electrical connections themselves (*NFPA 79 2007 edition (13.4.3.1.1)*). Permanent conductors not in a raceway shall be securely fastened at least every 6 inches using cable ties or other appropriate means.

- All conductors shall be prevented from chafing against any sharp edges (*NFPA 79 2007 edition (13.5.1.2)*).
- Proper use of colors for electrical power source wiring (e.g. red and black for DC + and −, black and white for AC “hot” and “neutral”, green for earth ground) (*NFPA 79 2007 edition (13.2)*). Colored tape is permissible at both ends of a wire whose insulation is not of the right color.

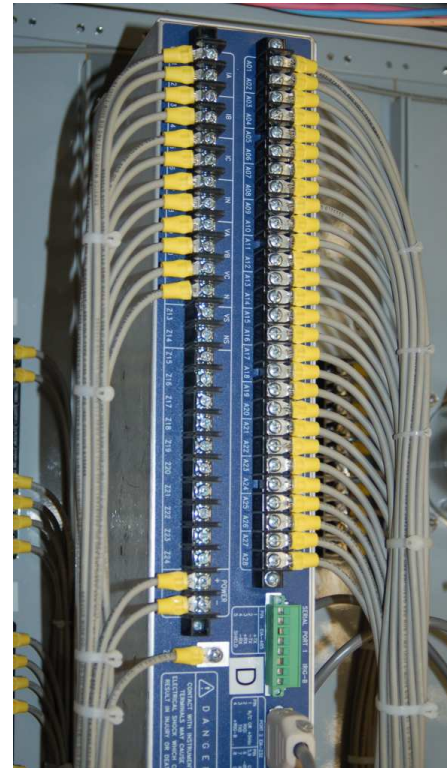
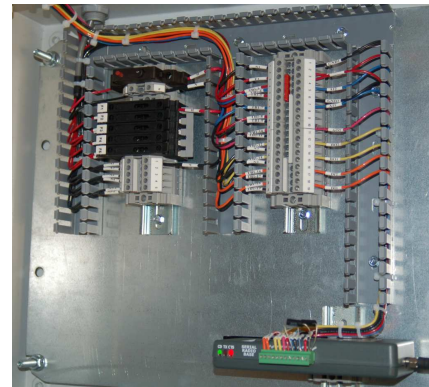
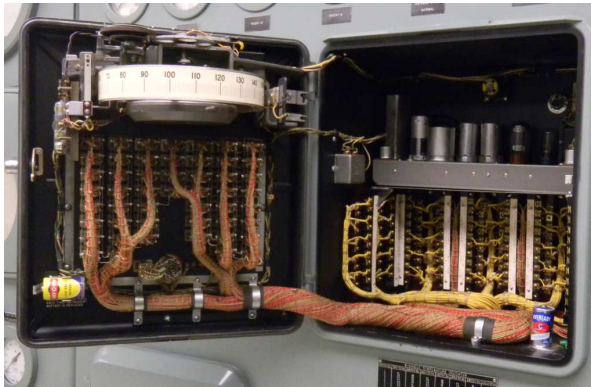
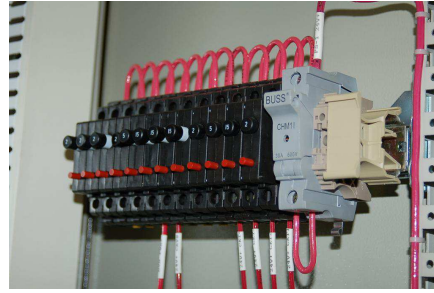
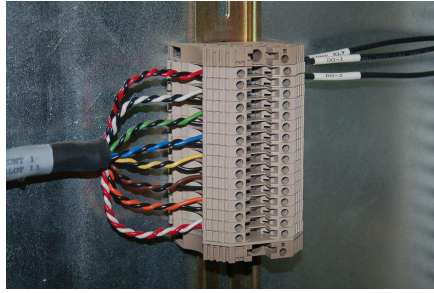
Other wiring and connections

- Proper wire sizes and insulation ratings throughout (e.g. sufficient wire gauge for the expected current, insulation over-rated for the highest voltages expected) (*NFPA 79 2007 edition (12.5)*).
- Compression terminals – crimping of solid wire, component leads, or stranded wire that has been solder-tinned, is prohibited. The conductor shall extend a minimum of flush with, and a maximum of one (1) wire diameter beyond the conductor crimp edge. No protruding wire strands outside the terminal barrel. (*NASA-STD-8739.4*)
- No splices allowed between terminals (*NFPA 79 2007 edition (13.1.2.1)*).
- No solid wire allowed where wire motion is possible, to prevent metal fatigue from vibration and other mechanical stresses. Only stranded wire shall be used for unrestrained wire runs, wires running between components not rigidly mounted to each other or to the same rigid frame, etc. (*NFPA 79 2007 edition (12.2.4)*)
- Only solid wires shall be wrapped around screw terminals, and this shall be clockwise. Wrap distance shall be between 180° and 270° (between $\frac{1}{2}$ and $\frac{3}{4}$ turn).
- Attached wires shall withstand being lightly pulled with fingers.
- Wire insulation shall be intact (i.e. no bare wires anywhere).
- After insulation removal, the remaining conductor insulation shall not exhibit any damage such as nicks, cuts, or charring. Conductors with damaged insulation shall not be used. Scuffing from mechanical stripping or slight discoloration from thermal stripping is acceptable. (*NASA-STD-8739.3*)
- Panel wiring shall be neat in appearance.
- Multiple conductors extending beyond an enclosure or panel shall be bundled together as a multi-conductor cable wherever possible.
- No use of solderless breadboards on permanent assemblies; use only for prototyping.
- No use of tape as electrical insulation; use heat-shrink tubing instead.
- Cables shall not be bent below the minimum recommended inside bend radius (6 diameters for flexible coaxial cable, 3 diameters for multi-wire harnesses 10 AWG and smaller). (*NASA-STD-8739.4*)

Soldered connections

- Visual Appearance – the appearance of the solder joint surface shall be smooth, nonporous, undisturbed and shall have a finish that may vary from satin to bright depending on the type of solder used (*NASA-STD-8739.3*). Overheated solder has a dull, gray, frosty and/or crystallized appearance (*NASA-STD-8739.2*).
- Solder Coverage – the molten solder shall flow around the conductor and over the termination areas. (*NASA-STD-8739.3*)
- Tinning – tinned surfaces, which are to become part of the solder termination, shall exhibit 100% coverage. When tinning stranded wires, the solder shall completely wet the conductor, penetrate to the inner strands, and exhibit 100% coverage. Wire strands shall remain distinguishable. Wicking of flux or solder shall be minimized. (*NASA-STD-8739.3* and *NASA-STD-8739.4*)
- Minimum Insulation Clearance – the insulation shall not be embedded in the solder joint. The contour of the conductor shall not be obscured at the termination end of the insulation. (*NASA-STD-8739.3*)
- Maximum Insulation Clearance – the insulation clearance shall be less than two wire diameters, including insulation, but in no case shall permit shorting between adjacent conductors. Insulation clearance shall be referenced from the first point of contact of the conductor to the terminal. (*NASA-STD-8739.3*)
- Mechanical Support and Strain Relief – wire bundles shall be supported so that the solder connections are not subjected to mechanical loads. Conductors shall be provided with sufficient slack to preclude tension on the solder termination or conductor. (*NASA-STD-8739.3*)
- Through-hole component leads terminated straight through a PCB shall extend 0.5 mm (0.020 in) to 2.29 mm (0.0900 in.) beyond the pad surface. Leads may be bend up to 30° from the vertical plane to retain the part during soldering. (*NASA-STD-8739.3*)
- Component bodies shall not be in contact with soldered terminations. (*NASA-STD-8739.3*)
- The radius of a bend in the lead of a component shall not be less than the lead diameter or lead thickness. (*NASA-STD-8739.3*)

Exemplar wiring (professional)



Exemplar wiring (student)

