IETTI-102 – DC Circuit Projects (Semester 1 PROJECTS)

NAME: _____ Last update 18 September 2026

Duration	Project	Score
All semester	Career preparation	
First 6 weeks	Development Board with power supply	
Last 9 weeks	9-week DC concepts project	

Essential information about this course:

- The purpose of this entire program is to empower you with knowledge, skill, and habits for your chosen craft, and doing your own work is absolutely necessary to that end. Relying on other people and/or artificial intelligence (AI) to read, write, design, plan, analyze, diagnose, or in any other way *think for you* defeats this purpose and will be considered plagiarism. Appropriate help always sharpens and never replaces a person's own ability to think and to do. Bear this in mind both when seeking help and when assisting classmates!
- The difference between *education* and *training* is learning to reason from principles versus following instructions. This course focuses on *design* and *project management*: turning theoretical knowledge into practical systems, budgeting time and resources to bring those systems to life. In keeping with the educational focus, these projects are not pre-designed but are planned by you in conjunction with the instructor. You will carefully document your plans, your work, and your system's critical information in the same manner technicians document projects on the job.
- More than any other type of course in this program, project courses provide opporunity for you to customize your learning, as you may choose projects targeted to specific interests and career choices.
- Assignments and assessments are just means to an end, and that end is learning. Similarly, grades, certificates, and degrees are just symbols of that same end. Prioritize *learning* and you will do well on your assignments and assessments, and your grades will reflect that. If you instead treat activity completion as the goal and grades as a prize, you'll not only sacrifice learning but also struggle to complete the assignments and obtain the grades you desire. Don't confuse the means versus the end; don't chase symbols in lieu of what they're supposed to represent.
- The final score is a simple average of all project scores, 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 by the same standard as other assessments: *accurate answers supported by sound reasoning.*
- Late completions of work will result in point deductions. Demonstrations of unprofessional behavior will trigger private meetings with your instructor(s).
- 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, but most students choose to do their hands-on project work on Fridays during our All-Lab sessions. *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, (4) document data neatly and accurately, and (5) double-check their work for correctness before submitting for assessment.

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 IETTI-101 (DC 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.

Course learning outcomes

- Write a résumé and cover letter suitable for submission to an employer. (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 DC, semiconductor, and basic digital circuits, 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 (i.e. a Project Journal) including test results, schematic diagrams, and summary of accomplishments. (Addresses Program Learning Outcomes 1, 6)

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
$5 mechanical pencil and eraser	X	X	X	X	X	X	X	X	X	X	X	X
$5 permanent marker			X			X			X			X
$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
$190 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
$15 utility knife			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: text editor		X			X			X			X	
$0 software: `NGSPICE` circuit sim.		X			X			X			X	
$0 software: `WSL`	X	X		X	X		X	X			X	
$0 software: `tshoot` fault sim.	X	X		X	X			X			X	
$0 software: `sp.c` simulator	X			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 – we use computers every day for applications such as teleconferencing software (e.g. Zoom), document reading and creation, coding, and circuit simulation. Having your own portable computer is therefore essential. Most operating systems, hard drive capacities, RAM memory sizes, and screen sizes are appropriate, but your computer must have a keyboard and mouse (i.e. no tablets). Avoid ChromeBooks. Useful but non-essential features include an RJ-45 Ethernet port and multiple USB ports.

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. Cost is a strong function of accuracy, additional features, frequency range, and safety ("Category" ratings for over-voltage exposure). The Fluke model 17B+ is an excellent choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. The best *minimal-cost* multimeter I've found is the model DT-830B which sells for less than $20, with the test leads being the weakest component (but easily upgraded).

Oscilloscope – 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 IETTI-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 instead. 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.

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++` and Microsoft's `VS Code` are both excellent options.

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 upgrade`
- `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 one "tar" file you unpack and compile using the following three commands within a Unix-type operating system or within `WSL`. The fourth command runs the application:

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

sp.c – this is a specialized circuit-simulator program for series/parallel DC resistor circuit analysis practice. The download consists of a single C-language source file that you may paste into an online C compiler to run, or compile on your own computer within WSL. The first command compiles, and the second one runs:

- `gcc -o sp sp.c -lm`
- `./sp`

EETREF archive – several gigabytes of 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.

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.

All challenges and assessments related to your project work must demonstrate understanding of the underlying concepts. This means answers arrived at by guessing, or even correct answers accompanied by incorrect reasoning, will be counted as incorrect. If it is evident by repeated mistakes that you do not adequately understand the concepts involved, the instructor may refuse re-tries until after you have completed more preparatory work. This is not intended to be punitive, but rather to ensure you complete the activity with the full competence appropriate for your chosen career.

A failing (F) grade will be earned for the entire course for any behavior that would result in being fired from a job, including false testimony (lying), cheating on any assignment or assessment, plagiarism (relying on another's work instead of your own, including artificial intelligence), willful violation of a safety policy, habitual tardiness or absenteeism, theft, harassment, sabotage, destruction of property, or intoxication.

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 usually creates problems that are more difficult to solve than if the system were built and tested piece by piece.
- **Document** – draw a diagram before building any system, and use this to guide your analysis and design decisions. If and when you make changes to your circuit, update your diagrams accordingly. Also, have any other relevant documents available for reference, such as datasheets, tutorials, etc. A common mistake is to begin building systems without first sketching what is to be built, and also not using the documentation for troubleshooting.
- **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.
- **First Principles** – always apply First Principles 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 First Principles) 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.

Instructor guidelines

This course seeks to impart knowledge of and skill in the management of complex projects. Your job as the instructor is to assist students in the selection of projects relevant to their theoretical studies and manageable within the given timeframes of either 6 weeks or 9 weeks.

The first "project" in this course focuses on career preparation, the duration being the entire 15 weeks of the semester. Your task as the instructor is primarily to hold students accountable to the deadlines within this project. In some project courses students have a choice of whether to (re)-write their cover letters and résumés versus earning an industry-recognized certification, and in this you may need to advise students on which option might be best for them.

The second and third projects in this course involve the actual design, construction, testing, and documentation of real functioning projects. Here the instructor plays a pivotal role helping students select projects that are appropriate for the students' learning needs. All projects must be safe, legal, and relevant to each student's most recent explorations in theory, but beyond that the student is free to pursue projects matching their own interests and professional goals. This is an excellent opportunity for students to customize their own education, in that they may choose projects directed toward specific career paths. For example, a student with a keen interest in biomedical electronics may opt to build projects related to human body monitoring; a student interested in telecommunications may pursue projects related to radio transmission and reception; etc.

To this end, you should maintain an ongoing list of project ideas for students to choose from. Projects intended to remain with the college (e.g. promotional displays for visitors interaction) shall be funded by the college and not by students unless they so volunteer. Projects remaining the property of students shall be funded by students.

Often you will find the need to rein in student project scope, as student excitement may lead to the setting of goals that are unattainable given the limited time to complete. If a student wishes to build a project that in your estimation will require more than nine weeks to complete, try to find ways to break that project into two smaller projects (one six-week and one nine-week).

On the first day of each project (All-Lab Day 01 for the 6-week project and All-Lab Day 07 for the 9-week project) you will meet with each student (or student team) to declare the project to be built, criteria for its functional performance, criteria for its adherence to safety and other standards (conformance), as well as reasonable goals for each All-Lab day. You will maintain a copy of these criteria and deliverables in your own records, as well as share a copy with each student or student team. Edits may be made to these deliverables and criteria, but *only* to accommodate unavoidable circumstances preventing their timely fulfillment. Deadlines passed and criteria unfulfilled due to poor time management on the student's part must carry the stated consequences, usually in the form of points deduction for lateness.

Students invariably require assistance during the prototyping, testing, and construction of their projects. Your role here is to be a consultant, offering practical advice and design tips based on your own professional experience. Ultimately, though, students are responsible for executing the work necessary to bring a project from mere concept to working form.

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 interviews. 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 – *Career Guide* and *Principles of Robust Technical Education* learning modules

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf`

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_robust.pdf`

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. This is a summary written in your own words describing what you see as marketable attributes common to those job descriptions. 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 (i.e. don't just provide web hyperlinks), 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.

- **Written declaration of interest** in one or more career pathways and how you could explore and prepare for them. Your declaration should identify at least one specific employer located in an area you already live in or would like to live in. Your expressed interest may guide future project choices, as the projects students do in this program are mostly chosen by the students and may be targeted to specific learning objectives. The *Career Guide* module outlines several career pathways in the "Jobs and industry sectors" section of the "What is Electronics?" chapter, and the *Principles of Robust Technical Education* module has an entire chapter called "Plans of study" showing how students in this program may customize their education for specific career trajectories.

- **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.

- Create a **résumé** optimized 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. The *Career Guide* module contains advice on writing cover letters and résumés.

- Collect a **letter of recommendation** for yourself, from a former supervisor, co-worker, teacher, coach, counselor, or other direct acquaintance in a position to attest to your work ethic and general employability. The letter must be written and authenticated (e.g. signed) by the person recommending you.

PROJECT: Career Preparation **NAME:** _____

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)
◯ Explain how project is graded and identify deadline dates ◯ Submit full text of an electronics technician job description ◯ Submit full text of another electronics technician job description ◯ *Neither* job description from an employer on our TAC	Day 8 of semester (worth 5%)
◯ Submit written summary of attributes sought by multiple employers ◯ Attach all job descriptions informing your summary ⊙ Employer(s) *not* represented on our TAC	Day 18 of semester (worth 10%)
◯ Submit written declaration of personal career interest(s) ◯ Identify at least one employer in the field(s) you choose	Day 30 of semester (worth 25%)
◯ Submit rough draft of résumé in PDF format ◯ Submit rough draft of cover letter in PDF format ◯ Attach job description targeted by résumé and cover letter	Day 40 of semester (worth 10%)
◯ Submit cover letter in PDF format with no errors ◯ Attach job description targeted by letter	Day 55 of semester (worth 20%)
◯ Submit résumé in PDF format with no errors ◯ Attach job description targeted by résumé	Day 65 of semester (worth 10%)
◯ Submit letter of recommendation from personal or professional reference (authenticated)	Day 70 of semester (worth 10%)
◯ Present written summary of attributes sought by employers to all participants at the TAC meeting	TAC meeting day (worth 10%)

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 during the TAC meetings:

- Avista Utilities
- British Petroleum (BP Cherry Point refinery)
- CCI/Speer
- Clearwater Paper
- Fisher Systems
- Hillcrest Aircraft Company
- Idaho Forest Group
- Micron
- On Semi
- POWER Engineers, Inc.
- Raute-Metriguard
- Schweitzer Engineering Laboratories (SEL)
- Taurus Power / Pacific Northern Environmental
- Tri-State Memorial Hospital
- Washington Alarm

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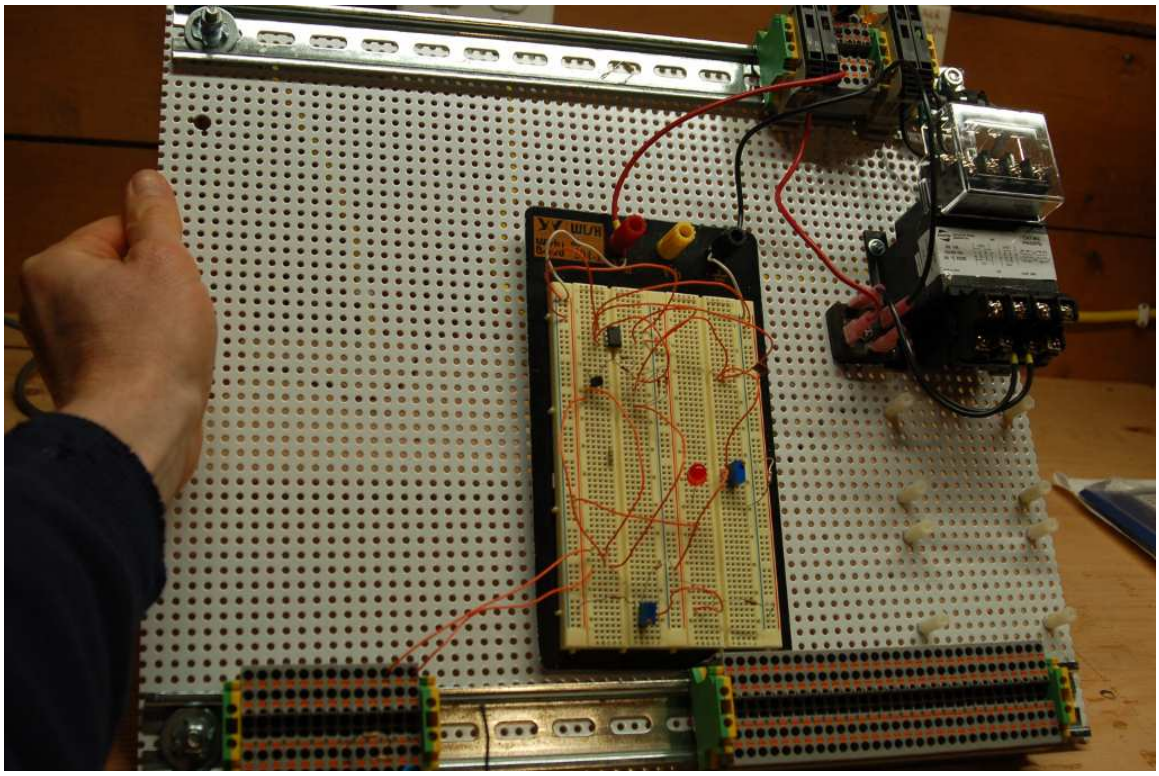
PROJECT: Development Board with power supply

For this project you will construct and test a *Development Board* useful for constructing experiments and projects throughout this program. A photograph of a typical Development Board is shown here as an example of what you will build:



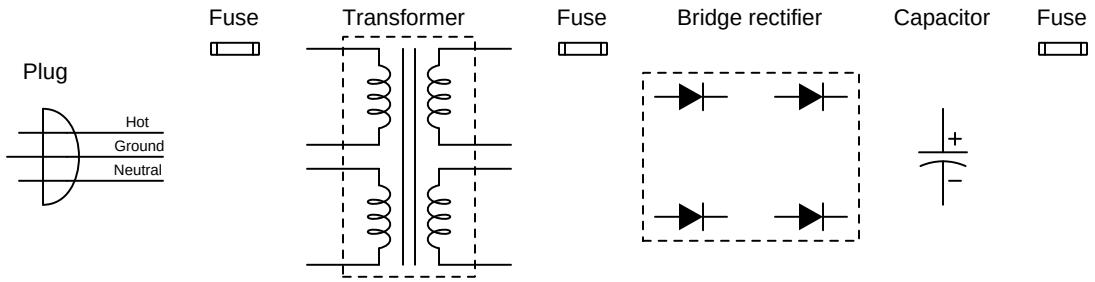
This consists of a perforated metal plate equipped with metal *DIN rails* upon which will be attached terminal blocks, fuse holders, and other electrical components. The board also hosts a *transformer*, *rectifier*, and other components necessary to make a simple AC-to-DC *power supply* capable of delivering safe, low-voltage DC electricity to energize circuits you will build. Enough space exists in the center of the panel to host a *solderless breadboard* for convenient construction of electronic circuits using "through-hole" style components.

In this photograph you can also see eight nylon *standoffs* threaded into perforations which were tapped with 6-32 machine screw threads. These standoffs are ready to accept *printed circuit boards* you may design and have etched for you by a PCB supplier, for more advanced circuitry such as *DC voltage regulators*, *oscillators*, and other accessories useful in experimental electronic work.

Your Development Board will serve as a sort of portable laboratory useful to you throughout all semesters of this program, and it is your personal property to keep and maintain. Cost of repairs and for any additional features you might add to it later (e.g. signal generator) are solely your responsibility. It is advisable that you write your name on the back of it for identification.

PROJECT: Development Board with power supply

The transformer provided to you for this project has two primary windings and two secondary windings, its purpose being to "step down" 120 Volt AC power from a standard wall power receptacle to a much safer level of AC voltage (typically either 12 or 24 Volts) suitable for energizing experimental circuits and small projects. This transformer will connect to a bridge rectifier circuit to convert AC into DC and also to a filtering capacitor, for the purpose of providing "filtered" DC output. An incomplete schematic diagram appears below, and you will need to research how these components interconnect to form a complete AC-DC power supply circuit. Completing this schematic consists of sketching in all wire connections between components and also labeling component wire colors, based on information you will find in the *Brute-Force Power Supplies* learning module. You also get to choose where to install a switch for on/off control:



Part of the work you will do on this project is performing both *conformance* and *functional* tests on your power supply circuit. A "conformance" test assesses compliance with an independent standard such as electrical safety. A "functional" test assesses the project's ability to meet its practical goals. Both sets of tests apply to the prototype circuit as well as the final circuit. In future projects you will be able to decide some of these criteria for yourself, but for this project it must meet the standards set forth for you here:

- **Conformance test:** meet all of the qualitative standards listed in the "Construction Standards" section near the end of this document.
- **Conformance test:** measure electrical resistance from the plug's ground prong to all metal surfaces on the Development Board to ensure 0.1 Ω or less of resistance throughout. (Note that *some* consumer-grade power cords often have a few tenths of an Ohm of resistance in the ground wire alone, making the industrial 0.1 Ohm maximum standard unattainable. Check your cord before committing it to use in your project!) *Document this measurement every time you test for conformance to this standard.*
- **Functional test:** measure DC voltage output by the power supply circuit as it is energizing a load passing 50% of the circuit's maximum rated current. *Document this measurement every time you test this function.*
- **Functional test:** measure AC "ripple" voltage output by the power supply circuit as it is energizing a load passing 10% of the circuit's maximum rated current. *Document this measurement every time you test this function.*

Information regarding AC power wiring (e.g. "hot" versus "neutral" versus "ground" conductors) may be found in the *Electrical Hazards* learning module.

You will not find a maximum rated current for the power supply circuit listed here, but you may determine that value based on the maximum advertised current ratings of the transformer's secondary windings, the diodes comprising the bridge rectifier portion of the circuit, the terminal blocks used to marshal the wiring, and the wire conductors used to connect these components to each other. Current ratings for any other components conducting the load current (e.g. optional power switch, optional voltage regulator) must also be considered. The least of these ratings will be the power supply circuit's maximum current rating. Individual component ratings will be found in *datasheet* documents published by those components' manufacturers.

PROJECT: Development Board with power supply **NAME:** _____

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

Instructor certifies each deliverable's completion. Every test must either be directly witnessed by the instructor or photo/video-recorded, and may be repeated as necessary.

Deliverables	**Deadline** (by 4:00 PM)
◯ Explain how project is graded and identify deadline dates ◯ Securely fasten "feet" to corners of Board ◯ Securely fasten DIN rails to Board ◯ Tap 6-32 threads in holes for four PCB standoffs (1.75" × 2.75") ◯ Attach twenty-five pass-thru terminal blocks to DIN rails ◯ Attach knife-style switch block to DIN rails ◯ Attach end-blocks and grounding terminal blocks to DIN rails ◯ Attach three fuse blocks to DIN rail	All-Lab day 1 (−5% per day if late)
◯ Research "brute force" AC-DC power supply circuit designs ◯ Submit a complete schematic diagram ◯ Identify costs of all power supply circuit components ◯ Download datasheets for all power supply circuit components ◯ Securely fasten AC power cord to Board (refer to "Construction Standards" pages) ◯ Securely fasten transformer to Board	All-Lab day 2 (−5% per day if late)
◯ Complete all 120 VAC wiring (from plug to transformer primaries) ◯ Test power wiring for safety prior to power-up (refer to *Power wiring* section of "Construction Standards")	All-Lab day 3
◯ Decide where knife switch goes in your circuit (multiple possibilities!) ◯ Complete all low-voltage wiring (from transformer to capacitor) *Use four terminal block sections for secondary winding terminations* ◯ Identify and explain *all* relevant Construction Standards	All-Lab day 4
◯ Finalize construction of AC-DC power supply circuit ◯ Passes Construction Standards inspection (−5% per re-work) ◯ Passes all Conformance tests (−5% per re-work) ◯ Passes all Functional tests (−5% per re-work)	All-Lab day 5
◯ Submit accurate schematic diagram ◯ Submit completed Project Journal (must contain all Conformance and Functional test data) ◯ Additional objectives (see "Project Grading" page)	All-Lab day 6 (−5% per day if late)

PROJECT: Development Board with power supply

Project grading

The standard for projects is mastery of skill and technique. You are welcome 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!

All tests and inspections will be done under the instructor's observation to ensure you understand each element of those tests and inspections. A "re-work" is where work that fails a test or inspection results in a penalty and must be re-done, then re-tested/inspected. Missed deadlines will result in a -5% penalty per school day. If working as a team, these penalties apply according to the team contract. If the project is incomplete by the deadline date (e.g. any test criteria unsatisfied, any required documentation missing, etc.) the score will be capped at a *maximum* of 50% with -5% deducted per school day until all is complete, unless due to accidental component failure in which case only the -5% per day applies.

You should maintain all your documentation in a single document, ideally an electronic document that is easily shared and archived. An important part of this documentation is your "Project Journal" where you describe your progress and accomplishments by date. 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.

This same (single) document should contain all your Conformance and Functional test documentation, showing what tests you conducted, on what date(s), with measured results recorded in any appropriate format. Your schematic diagram may be hand-drawn or drafted using computer software, your choice. If you prefer hand-drawing schematics but would still like to make your document electronic in nature, you may photograph or scan your hand-drawing and paste that image into the electronic document.

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.

file wp_0013

PROJECT: 9-week DC project

For this project you will design, prototype, test, construct, and document a project incorporating DC and/or digital circuitry. A recommended application is for one of the permanently-installed systems within the EET lab room, but other applications are possible so long as the project relates closely enough to the topics in the corresponding Theory and Experiments courses (IETTI-101 and 103, 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.

Suggested project ideas include:

- Electronic test equipment (e.g. analog VOM, regulated DC power supply)
- Electronic fuse (resettable overcurrent protection circuit) for Development Board
- Re-wire Development Board for split +V/−V DC output with dual adjustable voltage regulators
- Sensitive audio detector (enabling you to *hear* electricity!)
- Thermionic heater/cooler
- Comparator-based oven temperature controller
- Human-powered electrical generator (e.g. bicycle/handcrank-driven)
- Battery charge controller using three-terminal regulator IC
- Small-scale solar power system for powering electronic devices in remote locations
- Strobe light based on 555 timer IC and bright LED array
- Rebuild an existing device/system with sufficiently complex reverse-engineering/re-design needs

PROJECT: 9-week DC project **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 inspections and tests 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)
◯ Select project ◯ Explain how project is graded and identify deadline dates ◯ Identify Construction Standards relevant to this project ◯ Identify other Conformance criteria (e.g. safety, reliability) ◯ Identify Functional criteria (e.g. features) ◯ Submit prototype design (e.g. rough-draft schematic) ◯ Identify deliverables for each All-Lab day ◯ Locate/order components, materials, and other supplies ◯ [Team project only] Write, sign, and submit Team Contract	All-Lab day 7 (−5% per day if late)
◯ All-Lab day 8 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 9 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 10 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 11 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 12 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 13 deliverables; submit today's Project Journal entry	(−5% per day if late)
◯ All-Lab day 14 deliverables; submit today's Project Journal entry ◯ Passes Construction Standards inspection (−5% per re-work) ◯ Passes all Conformance tests (−5% per re-work) ◯ Passes all Functional tests (−5% per re-work)	(−5% per day if late)
◯ All remaining deliverables ◯ Project Journal containing *all* project data, plus all PCB/code files ◯ Test-point/code challenge (−5% per re-work) ◯ Additional objectives (see "Project Grading" page)	All-Lab day 15 (−5% per day if late)

PROJECT: 9-week DC project

Project grading

The standard for projects is mastery of skill and technique. You are welcome 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!

All tests and inspections will be done under the instructor's observation to ensure you understand each element of those tests and inspections. A "re-work" is where work that fails a test or inspection results in a penalty and must be re-done, then re-tested/inspected. Missed deadlines will result in a −5% penalty per school day. If working as a team, these penalties apply according to the team contract. If the project is incomplete by the deadline date (e.g. any test criteria unsatisfied, any required documentation missing, etc.) the score will be capped at a *maximum* of 50% with −5% deducted per school day until all is complete, unless due to accidental component failure in which case only the −5% per day applies.

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 "test-point/code challenge" is an assessment performed live with the instructor, where the instructor probes your understanding of the system and the accuracy of your schematic diagram and code documentation by challenging you to: (1) present a pre-written list of important test-points in your circuit with expected signal ranges for normal operating conditions and verify with live measurements, (2) predict and verify how those test-point signals vary as particular conditions change, and (3, for programmable projects only) explain the purpose of particular lines of code and/or the effects of editing those lines in specified ways. The instructor may challenge you to add new test-points to your schematic diagram and/or lines of code to your project and make predictions for them as well.

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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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 are 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:

Circuit design

- Decoupling capacitors – each and every integrated circuit shall have a decoupling capacitor of at least 0.1 μF near its DC power terminals for the purpose of stabilizing DC supply voltage. The same is true for loads generating noise, such as DC electric motors.
- Dedicated power sources – when possible, different power sources shall energize high-current loads versus low-current control circuitry, in order to avoid placing noise caused by the high-current loads onto the control circuit's power rails.
- Star-point power distribution – circuits that might interfere with one another through a shared power source shall have separate power conductors routing to that source.
- Keep high-current loops small – conductors carrying high currents shall run closely parallel to each other in order to minimize the "loop area" and thus minimize magnetic field creation.
- Twisted-pair and/or shielded cable – sensitive signals shall be protected from crosstalk by electrostatic shielding (grounded at one end only) and by twisting conductors (to minimize magnetic coupling).
- Conductor fault tolerance – circuits linked by plug-in conductors shall be designed to assume safe states in the event of disconnection.
- Consistent manual controls – clockwise knob rotation and upwards switch/slider shall result in "more" and/or "on" actions.
- System shall be generally reliable, functioning properly and safely under all reasonably-expected circumstances. In other words, *the system shall not be unreasonably fragile.*

General layout

- All components shall be mounted securely where applicable, such that they will not unintentionally loosen or detach with normal use.
- All manual controls (e.g. buttons, handles, knobs) and indicators (lamps, character displays) shall be accessible, clearly labeled, and function without undue effort. No user should have to struggle understanding or using any controls or indicators.
- Fragile components (e.g. heat-sensitive semiconductors) shall be easily accessed for replacement.
- Where exposure to liquid is expected, all electrical components and connections shall be suitably protected, and all enclosures rated for such exposure. Furthermore, all enclosure penetrations shall be located to as to make liquid ingress impossible (e.g. penetrations on the bottom side only to reject rain, waterproof seals on all else).

Fastening

- All components shall be securely fastened to the chassis so they cannot come loose or detached during normal operation. Adhesive tape is forbidden as a fastening method.
- All threaded fasteners shall be properly engaged and tightened, with all threads of each nut fully engaged with screw/bolt threads.

- 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.
- All components expected to run hot shall be located in such a way that their heat does not affect the function or longevity of any 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 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 0.1 Ω 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)*), and this includes installing bushings on all electrical fittings.
- All power conductors shall be properly colored according to American wiring conventions (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 correct color.

Other wiring and connections

- All other conductors shall have sufficient ampacity and insulation voltage ratings for their application (*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*)

- Compression-style wire splices are prohibited between terminals (*NFPA 79 2007 edition (13.1.2.1)*).
- Solid wire is prohibited 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 direction shall be clockwise. Wrap distance shall be between 180^o and 270^o (between $\frac{1}{2}$ and $\frac{3}{4}$ turn).
- Attached wires shall withstand being lightly pulled with fingers.
- All wire insulation shall be intact (i.e. no bare wires anywhere).
- All exposed traces, terminals, and solder joints on printed circuit boards shall not be able to make accidental contact with any conductive material.
- 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*)
- All exposed wiring shall be generally neat and not messy in appearance.
- Multiple conductors extending beyond an enclosure or panel shall be bundled together as a multi-conductor cable wherever possible, unless separation is necessary to avoid undesired signal coupling between conductors.
- Solderless breadboards are prohibited for permanent assemblies; acceptable only for prototyping.
- Tape is prohibited as electrical insulation; heat-shrink tubing shall be used 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*)
- Cables must contain enough extra length (*service loops*) to permit future re-termination, maintenance, and other physical adjustments made to the system.

Soldered connections

- Visual Appearance – the appearance of the solder joint surface shall be smooth, non-porous, 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*)

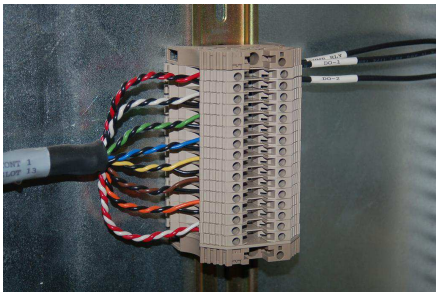
- Mechanical Support and Strain Relief – wire bundles shall be supported so that the solder connections are not subjected to mechanical loads. Conductors shall be provided with sufficient slack to preclude tension on the solder termination or conductor. (*NASA-STD-8739.3*)

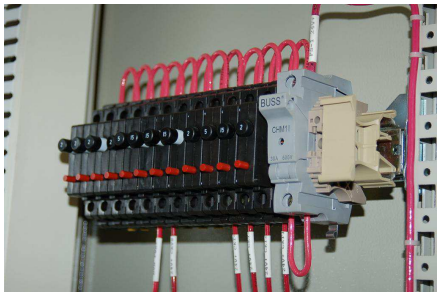
- Through-hole component leads and conductors terminated straight through a PCB shall extend 0.5 mm (0.020 in) to 2.29 mm (0.0900 in.) beyond the pad surface. Leads may be bend up to 30^o from the vertical plane to retain the part during soldering. (*NASA-STD-8739.3*)

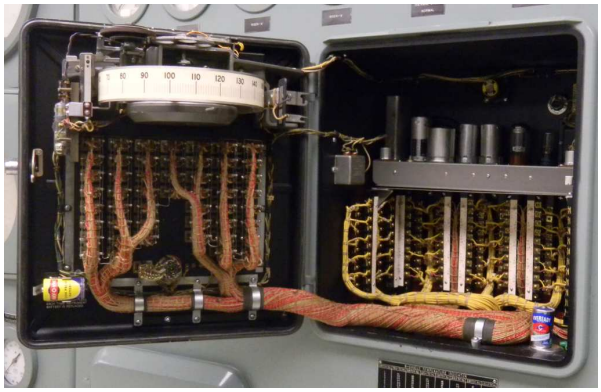
- Component bodies shall not be in contact with soldered terminations. (*NASA-STD-8739.3*)

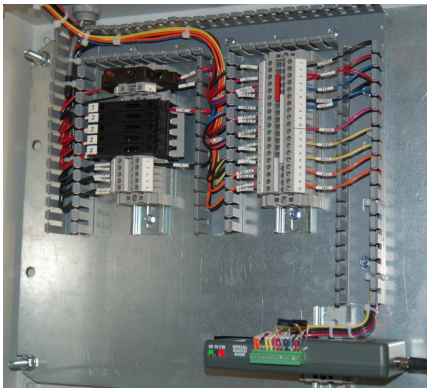
- The radius of a bend in the lead of a component shall not be less than the lead diameter or lead thickness. (*NASA-STD-8739.3*)

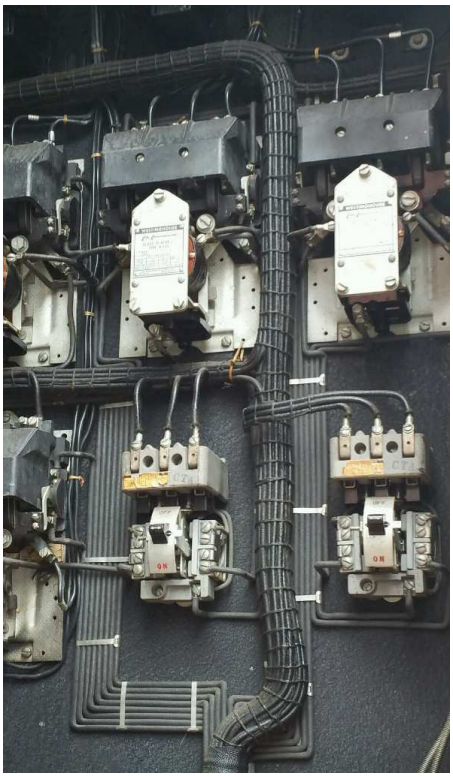
Exemplar wiring (professional)

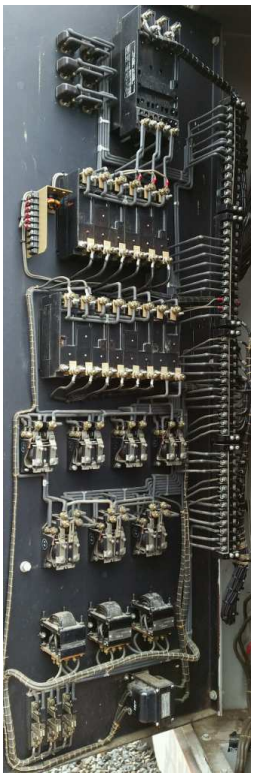


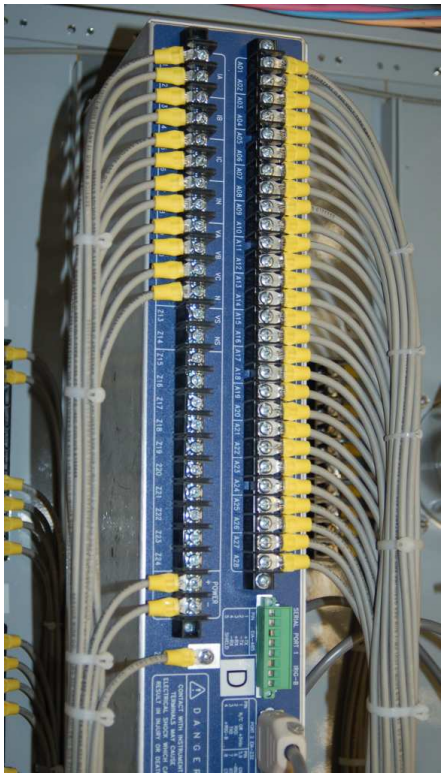






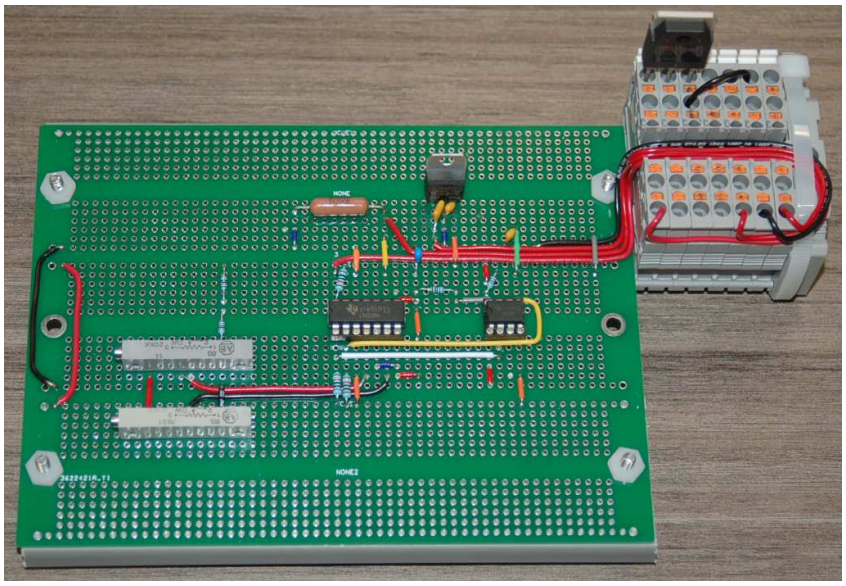






Exemplar wiring (student)

PWM pulse generator circuit constructed by Joe Archer in Fall 2023:



file wp_standards