

## EET ??? – ??? (PROJECTS)

NAME: \_\_\_\_\_

Last update 4 Jul 2020

Project	Score
Career preparation	
Development Board with power supply	
Solution for an external client	

### 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.
- You will be required to document all your work in a Project Journal to record important discoveries, device configurations, diagrams, test results, etc. just as R&D technicians must keep journals on new product testing and development. This Project Journal will not only prove valuable to your own project's completion but may also serve as a portfolio to show prospective employers.
- 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, (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 is a project-based course where students design, prototype, construct, test, and document practical ??? electronic systems. Project scope and functional criteria are chosen by consensus amongst the student, instructor, and external clients ultimately using the project.

## Course learning outcomes

- 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 ??? and ??? electronic 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 test results, schematic diagrams, project abstract, and summary of lessons learned. (Addresses Program Learning Outcomes 1, 6)

## 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.

<b>Source text</b> – <i>Career Guide</i> learning module
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<b>URL</b> – <a href="http://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf">http://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf</a>
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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](http://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.
- **Written notes from an informational interview** you conduct with an employer of electronics or related-skill technicians. This interview may be conducted face-to-face or by any form of teleconferencing (e.g. phone call, videoconference, etc.). The employer you interview must not be interviewed by any other classmate during this semester. In addition to any of the *suggested* informational interview questions listed in the *Career Guide*, you must include the “Required informational interview questions” listed on a subsequent page which are useful as feedback to the Technical Advisory Committee (TAC), the results of which will be shared at this semester’s TAC meeting.
- Creating or updating a **résumé** optimized for a current electronics technician job description, and including a copy of this job description for reference.
- Writing a **cover letter** directed to the appropriate individual for the same job description used to optimize the résumé.
- Collecting 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 signed by the person recommending you.
- Creating or updating a **professional portfolio** showcasing details of your work. Your portfolio may contain documentation from experiment and project work completed in this program, as well as examples of relevant work done outside of school. Online platforms such as [linkedin.com](http://linkedin.com) and blogs are useful for this purpose because any interested employer may easily access them.

**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)
<input type="radio"/> Explain to instructor how this project will be graded <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 (worth 5%)
<input type="radio"/> Forward copy of email sent to an employer requesting an informational interview <input checked="" type="radio"/> Employer <i>not</i> represented on our TAC <input checked="" type="radio"/> Employer <i>not</i> interviewed by any other classmates this semester	Day 12 of semester (worth 5%)
<input type="radio"/> Submit written summary of attributes sought by employers <input type="radio"/> Attach job description(s) informing your summary <input checked="" type="radio"/> Employer(s) <i>not</i> represented on our TAC	Day 18 of semester (worth 10%)
<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 35 of semester (worth 10%)
<input type="radio"/> Submit written questions and answers from informational interview <input type="radio"/> Attach interviewee's contact information (telephone and email) <input checked="" type="radio"/> Employer <i>not</i> represented on our TAC <input checked="" type="radio"/> Employer <i>not</i> interviewed by any other classmates this semester	Day 40 of semester (worth 20%)
<input type="radio"/> Submit cover letter in PDF format with no errors <input type="radio"/> Attach job description targeted by letter	Day 55 of semester (worth 20%)
<input type="radio"/> Submit résumé in PDF format with no errors <input type="radio"/> Attach job description targeted by résumé	Day 65 of semester (worth 10%)
<input type="radio"/> Submit letter of recommendation from personal or professional reference	Day 70 of semester (worth 10%)
<input type="radio"/> Submit professional portfolio which includes multimedia of your project work this semester	Day 76 of semester (worth 10%)

## **PROJECT: Career Preparation**

### **Required informational interview questions**

*(Be sure to introduce yourself in a professional manner, and let them know you are soliciting feedback for the Electronics Engineering Technology program to be presented at this semester's Technical Advisory Committee.)*

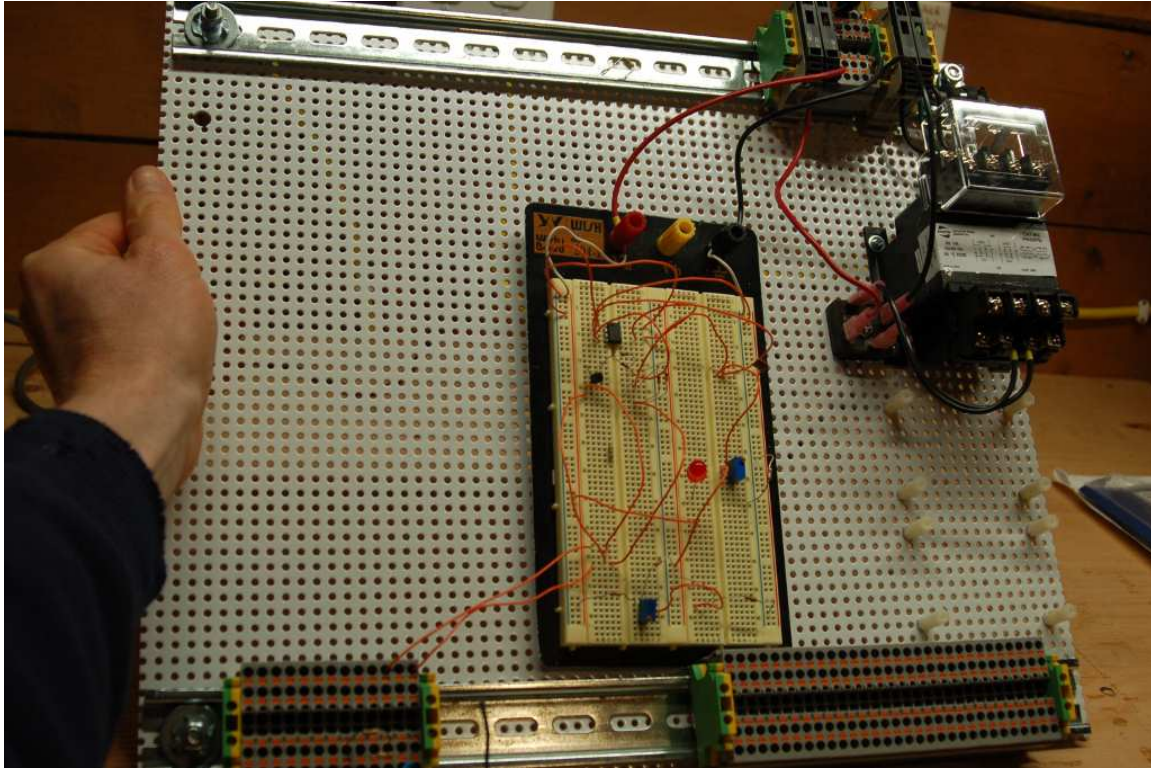
- Have you hired electronics technicians from this program in the past? If so, how satisfied have you been with their performance?
- What knowledge, skills, and habits do you most value in the technicians you employ?
- What should any prospective technician know in advance when considering employment at your company?
- Do you have any recommendations you would like me to convey to the program's Technical Advisory Committee?
- Would you be interested in attending future Technical Advisory Committee meetings?

*(Be sure to record their name and position within the company, their contact information (telephone and email), and to thank them for their time and interest in the program!)*

In addition to these required questions, you may freely sample from the list of suggested informational interview questions in the *Career Guide* and/or include your own questions. Remember that informational interviews have led to job offers, and so always conduct yourself in the utmost professional manner!

## 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.

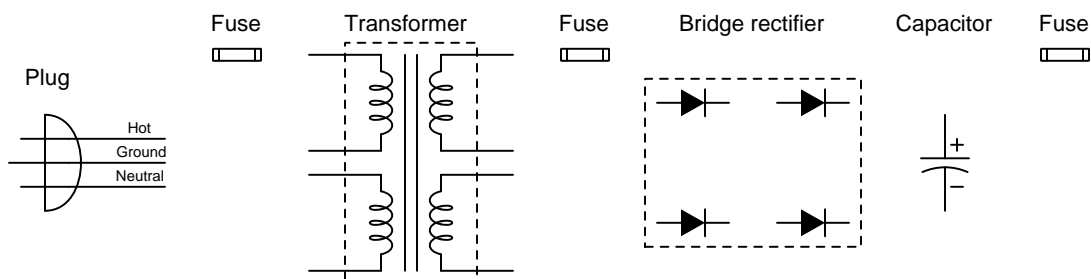
In this photograph you can also see eight nylon *standoffs* threaded into perforations which were tapped with 6-32 machine screw threads. These standoffs are ready to accept *printed circuit boards* you may design and have etched for you by a PCB supplier, for more advanced circuitry such as *DC voltage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



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  $0.1\ \Omega$  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  $0.1\ \text{Ohm}$  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)
<input type="radio"/> Explain how project is graded and identify deadline dates <input type="radio"/> Securely fasten “feet” to corners of Board <input type="radio"/> Securely fasten DIN rails to Board <input type="radio"/> Tap 6-32 threads in holes for four PCB standoffs (1.75" × 2.75") <input type="radio"/> Attach twenty-five pass-thru terminal blocks to DIN rails <input type="radio"/> Attach end-blocks and grounding terminal blocks to DIN rails <input type="radio"/> Attach three fuse blocks to DIN rail	All-Lab day 1 (–5% per day if late)
<input type="radio"/> Research “brute force” AC-DC power supply circuit designs <input type="radio"/> Submit a complete schematic diagram <input type="radio"/> Identify costs of all power supply circuit components <input type="radio"/> Download datasheets for all power supply circuit components <input type="radio"/> Securely fasten AC power cord to Board (refer to “Construction Standards” pages) <input type="radio"/> Securely fasten transformer to Board	All-Lab day 2 (–5% per day if late)
<input type="radio"/> Complete 120 VAC power wiring <input type="radio"/> Test power wiring for safety prior to power-up (refer to <i>Power wiring</i> section of “Construction Standards”)	All-Lab day 3
<input type="radio"/> Work day constructing AC-DC power supply circuit <input type="radio"/> Identify and explain <i>all</i> relevant Construction Standards	All-Lab day 4
<input type="radio"/> Finalize construction of AC-DC power supply circuit <input type="radio"/> Passes Construction Standards inspection (–5% per re-work) <input type="radio"/> Passes all Conformance tests (–5% per re-work) <input type="radio"/> Passes all Functional tests (–5% per re-work)	All-Lab day 5
<input type="radio"/> Submit accurate schematic diagram <input type="radio"/> Submit completed Project Journal (must contain all Conformance and Functional test data) <input type="radio"/> 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, 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. Any submitted work that is not correct (honest mistakes excepted) will count as "re-work" which results in a penalty, then you must re-do that work and have it inspected again. 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.

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.

**SAMPLE PROJECT IDEAS:** (??-based)

☐ *Complexity* = Low

- ???
- ???

☐ *Complexity* = Medium

- ???
- ???

☐ *Complexity* = High

- ???
- ???

## 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:

### General layout

- All components shall be mounted securely where applicable.
- 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 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.
- 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 [ $> 1.5 \text{ mm}$  ( $0.060 \text{ in}$ )] 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  $0.1 \Omega$  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

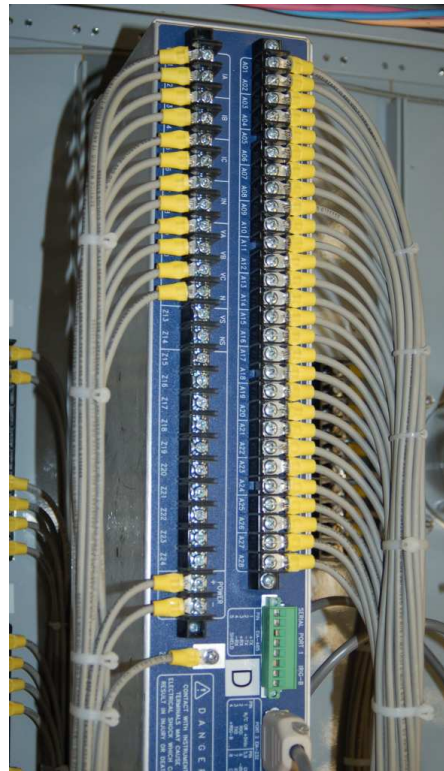
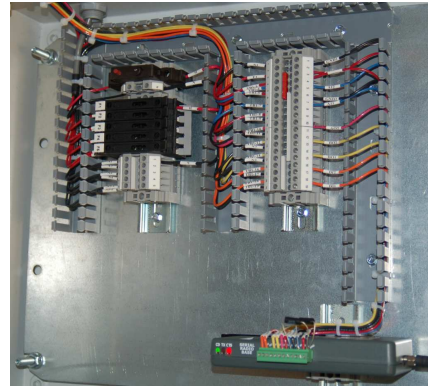
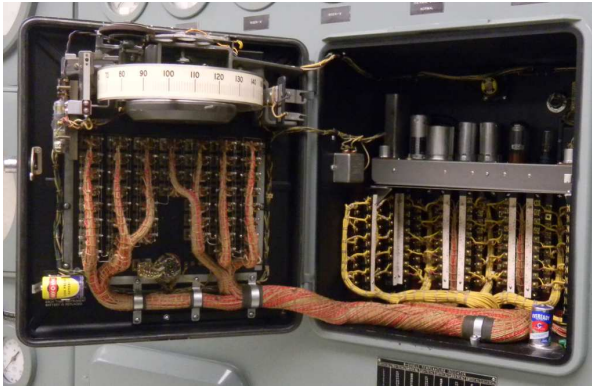
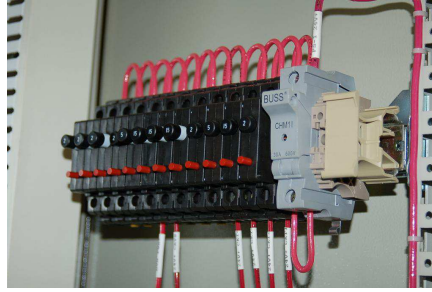
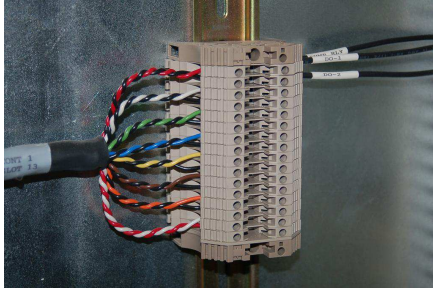
- All other conductors shall have sufficient ampacity and insulation voltage ratings for their application (*NFPA 79 2007 edition (12.5)*).
- Compression terminals – crimping of solid wire, component leads, or stranded wire that has been solder-tinned, is prohibited. The conductor shall extend a minimum 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° and 270° (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).
- 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*)

## 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 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° 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:

