

IETTI-225 – Advanced Electronics Experiments (Semester 4 EXPERIMENTS)

NAME: _____

Last update 2 April 2025

Activity #	Due by theory session #12	Score
01 Experiment	Memory-based system	
02 Assessment	Design, model, and build loaded voltage divider	
03 Assessment	Design, model, and build RC time-delay circuit	

Activity #	Due by theory session #24	Score
04 Experiment	Wired telemetry system	
05 Assessment	Capture and manually interpret a serial data frame	
06 Assessment	Troubleshoot wired telemetry system	

Activity #	Due by theory session #36	Score
07 Experiment	Radio telemetry system	
08 Assessment	Build, model, and test a custom inductor	
09 Assessment	Troubleshoot radio telemetry system	

Activity #	Due by theory session #48	Score
10 Experiment	Switch-mode power conversion system	
11 Assessment	Design, model, and build a transistor amplifier with specified gain	
12 Assessment	Troubleshoot power conversion system	

Activity #	Due by theory session #60	Score
13 Experiment	Measurement/control system	
14 Assessment	Design, model, and build a limited potentiometer network	
15 Assessment	Troubleshoot SCADA system	

16 Lab clean-up	Clean and organize the entire lab room	
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Essential information about this course:

- This is a laboratory course, but *the experiments are multi-concept systems rather than single-concept experiments.*
- These experimental systems follow concepts taught in that semester's theory course, which means the theory course outline and source texts are essential resources for you here.
- Half of your course grade comes from the number of attempts necessary to correctly complete each demonstration. Clarifying questions are welcome, but all results presented to the instructor will be assessed just like answers submitted on an exam.
- Half of your course grade comes from the number of attempts necessary to correctly complete each assessment activity (e.g. skills demonstrations and circuit troubleshooting). Just like the experiments, each assessment activity must be eventually completed correctly to pass the course.
- You should budget a minimum of 12 hours per week for this course. 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 experimental systems, (2) read system requirements carefully, (3) set reasonable goals, and (4) prioritize hands-on lab time.

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.

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.

Course description

This course reinforces the content of IETTI-223 (Advanced Electronics Theory) by way of experimental system design and construction, starting with only a block diagram and a general description of the system's intended function. Students then engineer all details of the system, building and testing it in stages. Students also apply foundational circuit principles to the diagnosis of simulated and real faults in these same types of circuits. Mastery standards applied to all experimental and diagnostic activities guarantee attainment of learning outcomes.

Course learning outcomes

- Design, construct, document, and test complex electronic systems based on general specifications and high-level design ideas developed in partnership with the instructor, these systems incorporating programmable memory, serial data communication networks, RF communication, power conversion circuits, and SCADA technology. (Addresses Program Learning Outcomes 1, 2, 3, 4, 5, 6, 7)
- Edit and write procedural code in a text-based programming language to simulate DC resistor circuits, resistor-capacitor delay networks, custom-wound inductors, and amplifier circuits. (Addresses Program Learning Outcomes 2, 4, 6, 7)
- Construct passive and active electronic circuits meeting specifications set by the instructor and demonstrate proper test equipment usage including multimeters, signal generators, oscilloscopes, and high-frequency measurement tools. (Addresses Program Learning Outcomes 4, 5, 6)
- Troubleshoot faulted wired telemetry systems, wireless telemetry systems, power conversion circuits, and SCADA systems from measurements taken at test points with circuit components and connections hidden from view. (Addresses Program Learning Outcomes 4, 6)
- Articulate diagnostic reasoning while troubleshooting these same circuits. (Addresses Program Learning Outcomes 1, 3)
- Create, maintain, and reference textual records (i.e. an Experiment Journal) documenting important principles and lessons learned. (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
\$150 USB-based oscilloscope		X	X		X	X		X	X		X	X
\$10 solderless breadboard (e.g. Busboard BB830)		X	X		X	X		X	X		X	X
\$25 grounding wrist strap		X	X		X	X		X	X		X	X
\$10 slotted screwdrivers (1/8”,1/4”)		X	X		X	X		X	X		X	X
\$10 Phillips screwdrivers (#1,#2)		X	X		X	X		X	X		X	X
\$10 jeweler’s screwdriver set		X	X		X	X		X	X		X	X
\$10 wire strippers, 18-24 AWG		X	X		X	X		X	X		X	X
\$10 needle-nose pliers		X	X		X	X		X	X		X	X
\$20 diagonal wire cutters		X	X		X	X		X	X		X	X
\$10 metal rule (inches & mm)		X	X		X	X		X	X		X	X
\$10 alligator-clip jumper wires (package of at least ten)		X	X		X	X		X	X		X	X
\$15 batteries: 6 Volt and 9 Volt		X	X		X	X		X	X		X	X
\$15 illuminated jeweler’s loupe		X	X		X	X		X	X		X	X
\$10 safety glasses			X		X	X			X			X
\$25-\$100 soldering iron (pencil-tip), 30 Watts or less			X		X	X			X			X
\$15 tube/spool of rosin-core solder			X		X	X			X			X
\$90 PLC I/O card		X			X			X			X	
\$15 microcontroller and software								X			X	X
\$0 software: Python interpreter	X			X			X			X	X	X
\$0 software: schematic editor		X	X		X	X		X	X		X	X
\$0 software: text editor		X			X			X			X	
\$0 software: NGSPICE circuit sim.		X			X			X			X	
\$0 software: WSL		X			X			X			X	
\$0 software: tshoot fault sim.		X			X			X			X	
\$0 software: PCB layout editor											X	X
\$0 software: packet-sniffing software										X	X	X
\$0 archive: EETREF collection	X			X			X			X		

Required Tools, Supplies, and Software

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

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

Multimeter – this is your first and most important electronic test instrument. At minimum it must measure DC and AC voltage, DC and AC current (milliAmpere range), resistance, and “diode check” voltage drop. Cost is a strong function of accuracy, additional features, frequency range, and safety (“Category” ratings for over-voltage exposure). The Fluke model 87-V is an excellent professional-grade choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. 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 – once too expensive for student purchase, entry-level USB-based oscilloscopes now cost less than a textbook. Pico Technology is an excellent brand, and their model 2204A comes with high-quality probes as well. Plugged into your personal computer using a USB cable, the Picoscope turns your computer’s monitor into a high-resolution oscilloscope display. Features include two measurement channels, 10 MHz bandwidth, built-in arbitrary waveform generator (AWG), ± 100 Volt over-voltage protection, digital “cursors” for precise interpretation of amplitude and frequency, meter-style measurement capability, Fast Fourier Transform algorithm for frequency-domain measurement, export ability to several graphic image formats as well as comma-separated variable (.csv) files, and serial communications signal decoding. Together with your multimeter, solderless breadboard and Development Board (which you will construct in the 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 or small roll. I recommend a fine-tipped soldering iron (15 Watts continuous power, although some with adjustable temperature controls may have higher power ratings to get up to soldering temperature more quickly) and a solder diameter 0.031 inches or smaller for doing fine printed-circuit board work. Also, keep the tip of your soldering iron clean by wiping it against a damp sponge or paper towel when hot, and not leaving it hot any longer than necessary. Hakko, X-tronic, and Lonove are all recommended brands.

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

Microcontroller – these courses are not brand- or model-specific, but the Texas Instruments MSP430 series is highly recommended for their powerful features, modern design, and programmability in multiple languages (assembly, C, C++, and Sketch). I particularly recommend the model MSP-EXP430G2ET “LaunchPad” development board (MSP430G2553IN20 microcontroller chip) with Code Composer Studio for the IDE software.

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 install build-essential`

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

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

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

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

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

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

[file eet_tools](#)

Grading standards for Experiment courses

Your grade for this course is based on percentage scores (in every calculation rounded *down* to whole-numbered values), with each category weighted as follows:

- Experiment scores = 50% (Note: all Experiments are mastery-based, which means they must be eventually completed at 100% competence in order to pass the course)
- Assessment scores = 50% (Note: all Assessments are mastery-based, which means they must be eventually completed at 100% competence in order to pass the course)

Please note the importance of completing all Experiments and all Assessments on or before their respective deadline dates. If any Experiment or Assessment is incomplete by the end of the school day of the deadline date, it will receive a 0% score. If any Experiment or Assessment is incomplete by the end of the last day of the course, you will earn a failing grade (F) for the course. All Experiments and Assessments must be complete by the end of the last day of the course to receive a passing grade for the course.

Carefully follow the instructions associated with each experiment! If there is a prescribed order, you must follow this order of steps or else you will receive a 0% score for that experiment. The same is true if you plagiarize any part of it (i.e. present someone else's work as your own). For every experiment there will be multiple demonstrations, explanations, and/or challenges you must complete in the instructor's presence, and these are all mastery-based which means they all must be completed with 100% competence. Multiple opportunities are given to master each, with a point deduction levied for every re-try. You are welcome and encouraged at any time to seek clarification from the instructor so that you understand what is being asked of you, but you are solely responsible for doing the work and solving the problems. This is similar to the policy during written exams in a Theory course: the instructor will happily clarify expectations, but will not solve the problems for you nor confirm if an answer is correct prior to scoring it.

Electronic submissions of Experiments and Assessments are acceptable for full credit. The standards are just as high for electronic submissions as for face-to-face demonstrations. For Experiments, video documentation of you completing all objectives in their proper order will count as full credit. For Assessments your work must either be videorecorded in one seamless take or performed on a live video stream so the instructor is able to ensure you are doing the work yourself with no aid.

This course is based on experiments and hands-on assessments, and does not have scheduled meeting 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.

If you must be late or absent, it is imperative that you contact your instructor as well as any classmates you may be coordinating with so plans may be adjusted. It is still your responsibility to meet all deadlines.

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

Getting help in the lab

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

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

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

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

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

Expectations for each experimental system

In the EET program the initial Experiments courses are based on small-scale experiments, each one designed to explore a single concept. Here in the later Experiments courses you build experimental *systems* involving multiple concepts, requiring research and design similar to that of real challenges on the job. The purpose of the introductory Experiments courses is to build competence in discrete skills; here the purpose is to develop a higher level of problem-solving and professionalism.

The systems you will build in this course borrow heavily from concepts and designs explored in previous courses, so you will find your previous coursework extremely useful as reference material.

Stand-alone demonstrations should be performed using *minimal* hardware – meaning the bare minimum of components connected together to perform each demonstration, ideally with that portion of the system functioning in complete isolation from all others. The purpose of this is to build the habit of building and testing large systems in stages which is a proven way to develop complex systems with as little troubleshooting as necessary. A deduction of -5% per re-try is levied on each unsuccessful stand-alone demonstration.

Complete system demonstrations must be performed after every stand-alone demonstration has been completed for that experimental system. All portions of the system must be in good working order, proven by having you demonstrate all bullet items listed for the complete system demonstration. If any portion of the complete system demonstration is faulty or otherwise incorrect, the instructor's inspection will stop and a deduction of -10% will be levied. You will then revisit your system and make all necessary corrections and reviews, and are welcome to re-try as many times as necessary. The same -10% deduction applies to all failed re-tries.

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

Each experimental system you build will be a testament to your knowledge and skill as an electronics technician, and will be thoroughly documented in your Experiment Journal which you may show to employers as a portfolio of your experimental capabilities.

As always, questions are welcome throughout the research, design, and construction process. You will never lose points for asking a question prior to an assessment, and your instructor will always clarify expectations so that you know what is being asked of you, but the moment you deem any part of your system ready the instructor's job is to grade your work. This is the same as on a job: when you present a finished product to a supervisor or client, it must actually be ready. The time to ask for clarification is before the inspection, not during.

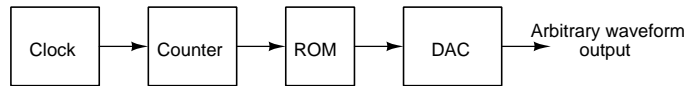
01 Experiment – waveform generator option

NAME: _____

DUE DATE: _____

Design and build an experimental *arbitrary waveform generator* using a nonvolatile memory IC to store numerical values describing the instantaneous amplitudes of a waveform at multiple points throughout its period. A counter will drive the address lines of the memory IC, and with the stored digital data driving a digital-to-analog converter to produce the waveform.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record a functioning clock pulse circuit suitable for driving the counter.

Instructor certifies – Demonstrate a functioning counter circuit suitable for driving the memory IC.

Instructor certifies – Interpret timing diagrams given in memory IC datasheet for both read and write operations.

Instructor certifies – Demonstrate writing data to the memory IC and reading data from it.

Instructor certifies – Demonstrate and record a functioning DAC circuit.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Output waveform exhibits the desired wave-shape
- Variable-frequency adjustment
- Expected harmonic content on the output (i.e. only significant harmonics present are those appropriate to the desired waveshape)
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

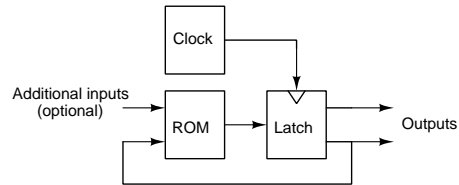
01 Experiment – finite state machine option

NAME: _____

DUE DATE: _____

Design and build an experimental *finite state machine* using a nonvolatile memory IC to store numerical values describing the next state.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record a functioning clock pulse circuit suitable for driving the latch.

Instructor certifies – Create a truth table and/or state diagram showing all states and their associated variables.

Instructor certifies – Interpret timing diagrams given in memory IC datasheet for both read and write operations.

Instructor certifies – Demonstrate writing data to the memory IC and reading data from it.

Instructor certifies – Demonstrate and record a functioning FSM sequence.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Variable-frequency clock signal
- Performs some practical or interesting function(s)
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

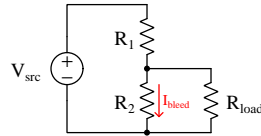
02 Assessment

NAME: _____

DUE DATE: _____

Design, build, and demonstrate a voltage divider network to energize a load with a specified output voltage from a voltage source of random value (e.g. a primary-cell battery), also writing a text-based computer program (e.g. C, C++, Python) modeling this same circuit and predicting its performance. You will be allowed to measure the voltage of the random source before beginning your circuit design.

This exercise tests your ability to properly design and build a loaded voltage divider circuit, use a multimeter to measure both voltage and current, properly organize all electrical connections, and write a computer algorithm to predict series-parallel DC circuit behavior.



The following components and materials will be available to you: lengths of **hook-up wire** ; assortment of **resistors** ; **potentiometers** ; and a **fixed voltage source** provided by the instructor. You must provide your own tools, digital multimeter (DMM), a computer with programming software installed, and solderless breadboard or terminal blocks as well as a copy of this page for your instructor to mark design criteria.

Source voltage (measured after instructor chooses source): _____ Volts

Load resistance (instructor chooses): _____ Ohms

Load voltage (instructor chooses): _____ Volts

Bleed current (instructor chooses): _____ Amperes

The measured bleed current and load voltage should deviate from the instructor-specified value by no more than the greatest tolerance of any of the resistors. The same is true for the results of your modeling program.

SEQUENCE: (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You write and test the modeling program; (3) Instructor observes your program's output while you correctly explain how the source code works; (4) You build and test your circuit (using a multimeter) without any power sources at all; (5) Instructor observes circuit energizing for the very first time; (6) You prove to the instructor that the circuit performs as predicted by your program, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we 1113

03 Assessment

NAME: _____

DUE DATE: _____

Design, build, and demonstrate a resistor-capacitor circuit that achieves a specified voltage between its output terminals within a specified range of time following the actuation of a switch, also writing a text-based computer program (e.g. C, C++, Python) modeling this same circuit and predicting output voltage at multiple points in time.

This exercise tests your ability to apply inverse-exponential functions to RC networks, use an oscilloscope to measure voltage over time, properly organize all electrical connections, and write a computer algorithm to predict RC network behavior.

The following components and materials will be available to you: **DC power supply** with variable voltage output ; an assortment of **capacitors** ; an assortment of **resistors** ; **switches** ; **potentiometers** ; **oscilloscope** ; and lengths of **hook-up wire**. You must provide your own tools, a digital multimeter (DMM), a computer with programming software installed, and a solderless breadboard or terminal blocks as well as a copy of this page for your instructor to mark design criteria.

Source voltage (instructor chooses) = _____ V

Output voltage trajectory (instructor chooses one) = ____ Rises or ____ Falls after actuation

Output voltage within time range (instructor chooses) = _____ V

Time range (instructor chooses) = between _____ seconds and _____ seconds

The performance of your circuit will be judged on whether or not the output voltage reaches the specified value at any time within the specified window, and whether this happens as it rises or falls. The performance of your modeling program will be judged by its output showing a series of printed voltage values calculated at different times covering at least the specified time period.

SEQUENCE: (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You write and test the modeling program; (3) Instructor observes your program's output while you correctly explain how the source code works; (4) You build and test your circuit (using a multimeter) without any power sources at all; (5) Instructor observes circuit energizing for the very first time; (6) You prove to the instructor that the circuit performs as predicted by your program, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we 1114

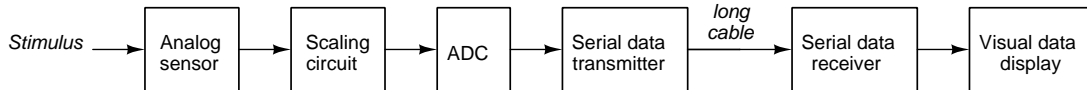
04 Experiment

NAME: _____

DUE DATE: _____

Design and build an experimental telemetry system sensing at least one channel of analog data and communicating that data in serial fashion to a visual display via a cable. A wide variety of stimuli may be considered for this system so long as its value may be independently verified by test equipment. A microcontroller with analog input and serial output capability may serve as the “ADC” and “Serial data transmitter” function blocks in one unit.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record sensor producing an analog signal in proportion to the intended stimulus.

Instructor certifies – Demonstrate and record scaling circuit properly conditioning the analog sensor’s signal to a form suitable for the analog-to-digital converter (ADC).

Instructor certifies – Demonstrate and record serial data being transmitted and received via the full-length cable, with communication parameters (e.g. bit rate, parity, device address, etc.) configured properly.

Instructor certifies – Demonstrate and record serial data being visually displayed in a form suitable for customer use.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Analog stimulus is accurately sensed and reported in practical units of measurement on the visual display, the accuracy of that displayed data judged by comparison with a measuring instrument sensing the same stimulus
- System provides for calibration adjustment if the reported data is in error
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

05 Assessment

NAME: _____

DUE DATE: _____

Using no instrument or tool other than a digital oscilloscope, properly interpret an RS-232 or RS-485 serial data frame arbitrarily chosen and transmitted by the instructor over a wired cable. You may reference any schematic diagrams for the serial data system, including pin assignments on connectors, terminal assignments on devices, cable wire colors, etc. The instructor will randomly (and secretly) set the transmitted bit rate, the number of data bits, and the ASCII character to be transmitted (from four possible characters that you choose). Only the parity type (even/odd/none) will be declared to you at the start of the assessment.

This exercise tests your ability to configure and use a digital oscilloscope to capture a transient serial data waveform, properly interpret voltage levels as bit states, and properly interpret the various portions of the data frame (e.g. start bit, stop bit(s), data payload, parity bit, etc.)

The following components and materials will be available to you: **digital oscilloscope** with probes, **9-pin serial cable**, and a **personal computer** with a 9-pin serial port and terminal emulator software installed. You must provide your own tools, a reference for ASCII codes, and a copy of this page.

Parity type (instructor chooses one) = ___ Odd ___ Even ___ None

Possible characters (student chooses four) = ___ or ___ or ___ or ___

Correct interpretation of **data payload** = ___ (ASCII character)

Correct interpretation of **bit rate** = ___

Correct identification of **other bits** = ___

SEQUENCE: (1) Instructor identifies which system you will perform your challenge on; (2) You configure and connect the necessary test equipment to that system with no power applied; (3) Instructor energizes circuit for the very first time; (4) You perform your tests/measurements for the instructor to compare against the standard.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we_1117

06 Assessment

NAME: _____

DUE DATE: _____

Troubleshoot a fault within a *wired telemetry* system. This system shall be constructed in such a manner that all circuit components and simulated faults at both ends of the cable must be hidden from view (e.g. covering them up with boxes or towels) but test points will be available for contact with instrument probes. A schematic diagram showing the system and its test points will be allowed for use during the troubleshooting exercise.

The measured stimulus must be adjustable while the fault is hidden from view, and there must be a test instrument showing the true value of this stimulus to compare against the value reported by the telemetry system. Possible faults include:

- Any cable failed open
- Any cable failed shorted
- Any component failed open
- Any component failed shorted
- Any component value altered
- Serial communication parameter set incorrectly

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

file we 1019

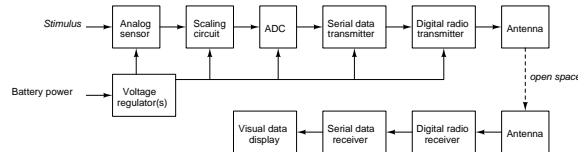
07 Experiment

NAME: _____

DUE DATE: _____

Design and build an experimental telemetry system sensing at least one channel of analog data and communicating that data in serial fashion to a visual display via radio, with all electronics on the transmitting end powered by a single battery. You are encouraged to use the same analog sensor and conditioning circuitry from the previous experimental system (wired telemetry), adding the radio transceivers and antennas to make a new system.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record serial data being transmitted and received across a cable (i.e. no radio), with communication parameters (e.g. bit rate, parity, device address, etc.) configured properly.

Instructor certifies – Demonstrate and record serial data being transmitted and received via the digital radio transceiver modules, with communication parameters (e.g. bit rate, parity, device address, etc.) configured properly.

Instructor certifies – Demonstrate how to optimize the physical dimensions of an antenna using appropriate test equipment (e.g. VNA on a bare antenna, or SWR meter or forward/reflected power meter on an antenna connected to a transmitter). *The instructor may challenge you a randomized problem to test your mastery of this concept!*

Instructor certifies – Demonstrate power conditioning circuit operating for several minutes with stable output voltage(s) and without overheating; calculate fresh battery life based on DC current draw and battery milliAmpere-Hour capacity.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Analog stimulus is accurately sensed and reported in practical units of measurement on the visual display, the accuracy of that displayed data judged by comparison with a measuring instrument sensing the same stimulus
- All power for the transmitting side supplied by a single battery
- System provides for calibration adjustment if the reported data is in error
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

file we_3005

08 Assessment

NAME: _____

DUE DATE: _____

Build and test an inductor with an arbitrary inductance value specified by the instructor. Enamel-coated magnet wire will be available to you, as well as an assortment of powdered-iron toroidal cores you may use for winding the inductor. In all likelihood you will not be able to *exactly* match the instructor's "target" inductance value because you will need to build your inductor with a whole number of turns. For this reason you will be asked to calculate the expected (achievable) inductance for the whole-number-value of turns that will come closest to that target value. Additionally, you will write a text-based computer program (e.g. C, C++, Python) modeling the amount of inductance for a user-specified number of turns.

This exercise tests your ability to accurately predict the number of wire turns necessary to create a specific amount of inductance given available core sizes and materials, properly wind wire around a suitable core, properly use test equipment to measure inductance, and write a computer algorithm to predict inductance. You may reference datasheets for any available magnetic cores stocked in the lab.

The following components and materials will be available to you: **vector network analyzer** (VNA) and/or **impedance analyzer**, **oscilloscope**, **signal generator**, **toroidal cores**, and **enamel-coated magnet wire**. You must provide your own tools, a digital multimeter (DMM), a computer with programming software installed, and a solderless breadboard or terminal blocks as well as a copy of this page for your instructor to mark design criteria.

Target inductance (instructor chooses) = _____ H

Achievable inductance (you predict) = _____ H

SEQUENCE: (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You write and test the modeling program; (3) Instructor observes your program's output while you correctly explain how the source code works; (4) You build and test your circuit (using a multimeter) without any power sources at all; (5) Instructor observes circuit energizing for the very first time; (6) You prove to the instructor that the circuit performs as predicted by your program, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

[file we_1122](#)

09 Assessment

NAME: _____

DUE DATE: _____

Troubleshoot a fault within a *radio telemetry* system. This system shall be constructed in such a manner that all circuit components and simulated faults at both ends of the radio link must be hidden from view (e.g. covering them up with boxes or towels) but test points will be available for contact with instrument probes. A schematic diagram showing the system and its test points will be allowed for use during the troubleshooting exercise.

The measured stimulus must be adjustable while the fault is hidden from view, and there must be a test instrument showing the true value of this stimulus to compare against the value reported by the telemetry system. Possible faults include:

- Any cable failed open
- Any cable failed shorted
- Any component failed open
- Any component failed shorted
- Any component value altered
- Serial communication parameter set incorrectly
- Digital radio parameter set incorrectly

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

file we_1023

10 Experiment

NAME: _____

DUE DATE: _____

Design and build an experimental switch-mode power conversion system. This may take the form of a DC-DC power converter, a DC-AC power inverter, a charge pump, or even a battery-management system utilizing transistor switching. You are welcome to use a switch-mode regulator IC in your design, but the selection, layout, and connection of all other components in the system (e.g. inductors, transformers, capacitors, diodes, transistors) must be your own doing.

Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record measurement of fundamental component parameters (e.g. inductance of inductors, capacitance of capacitors) using appropriate test equipment.

Instructor certifies – Demonstrate and record measurement of parasitic component parameters (e.g. resistance of inductors, resistance of capacitance) using appropriate test equipment.

Instructor certifies – Demonstrate and record power converter appropriately converting input power to output power (e.g. from DC to AC, stepping voltage/current up/down, etc.).

Instructor certifies – Demonstrate and record energy efficiency at three different load levels.

Instructor certifies – Demonstrate use of near-field probes to detect electric and magnetic emissions from your converter circuit. *The instructor may challenge you a randomized problem to test your mastery of this concept!*

Instructor certifies – Demonstrate and record filtering of electrical noise from your converter circuit, either noise conducted toward the source, or noise conducted toward the load.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Circuit fulfills basic power-conversion function(s); e.g. DC-AC, voltage/current transformation, etc.
- Precautionary test protocols applied throughout, as though the circuit harbored dangerous voltage levels
- Converter output voltage/current is appropriate for the load
- Electrical noise attenuated by filter network(s)
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

11 Assessment

NAME: _____

DUE DATE: _____

Design, build, and demonstrate a discrete transistor amplifier circuit exhibiting a pre-specified voltage gain. Additionally, you will write a text-based computer program (e.g. C, C++, Python) modeling the amplifier's input impedance, its output impedance, and its voltage gain based on user-specified component values.

This exercise tests your ability to properly design and build a transistor amplifier circuit, select components necessary to achieve a specified voltage gain, use a signal generator to properly stimulate the amplifier, use an oscilloscope to measure signal voltage and from those measurements infer voltage gain, properly organize all electrical connections, and write a computer algorithm to predict amplifier performance parameters. You will find the "Amplifier design example: swamped common-emitter" section of the *Single-Stage BJT Amplifiers* module tutorial to be helpful.

The following components and materials will be available to you: assortment of **resistors** ; **potentiometers** ; **capacitors** ; **batteries** ; and **discrete transistors**. You must provide your own tools, a digital multimeter (DMM), a computer with programming software installed, and your Development Board as well as a copy of this page for your instructor to mark design criteria.

AC voltage gain (instructor chooses) = _____ (unitless)

When demonstrating voltage gain in your powered amplifier circuit, you are free to choose whatever levels of test signal voltage you wish, and you are also welcome to make bias adjustments to ensure your amplifier is operating in Class-A mode (i.e. no visible distortion). All gain-setting component values must be fixed, however, from your building of the amplifier circuit prior to power-up. With bias and signal values properly adjusted, the exhibited gain should not deviate from the instructor-chosen specification more than $\pm 10\%$ based on component values selected/adjusted prior to power-up.

SEQUENCE: (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You write and test the modeling program; (3) Instructor observes your program's output while you correctly explain how the source code works; (4) You build and test your circuit (using a multimeter) without any power sources at all; (5) Instructor observes circuit energizing for the very first time; (6) You prove to the instructor that the circuit performs as predicted by your program, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

[file we_1123](#)

12 Assessment

NAME: _____

DUE DATE: _____

Troubleshoot a fault within a *switch-mode power conversion* system. A complete schematic diagram for the system will be allowed for use during the troubleshooting exercise.

- Any cable failed open
- Any cable failed shorted
- Any component failed open
- Any component failed shorted
- Any component value altered

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

file we 1025

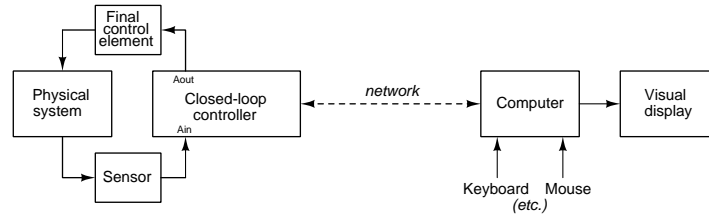
13 Experiment – control system option

NAME: _____

DUE DATE: _____

Design and build a Supervisory Control and Data Acquisition (SCADA) system implementing closed-loop control over some process variable, using a personal computer with a digital user interface (UI) for displaying this data, communicating all data over some form of digital serial network (e.g. RS-485, Ethernet, digital radio). Examples include remote control of electric motor speed, remote control over oven temperature, etc.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record a user interface (UI) of your own making remotely displaying analog data captured from the sensor via a digital network. Pre-existing data acquisition software and/or manufactured HMI hardware is not allowed for the UI.

Instructor certifies – Demonstrate and record your user interface (UI) exerting open-loop “manual” control over the final control element.

Instructor certifies – Demonstrate closed-loop “automatic” control of the physical system. Options include analog PID controller circuitry, a PLC equipped with analog inputs and outputs, a microcontroller equipped with ADC and DAC hardware, etc.

Instructor certifies – Demonstrate and record your user interface (UI) providing adjustable setpoint for closed-loop “automatic” control.

Instructor certifies – Demonstrate adjustable control parameters (e.g. hysteresis, thresholds, gain, integral time) affecting the quality of the closed-loop control.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Sensor measurement accurately displayed on UI in practical units of measurement
- Closed-loop control responds to UI setpoint changes and to physical (load) disturbances
- Closed-loop control continues when digital network communications becomes interrupted
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

file we_3010

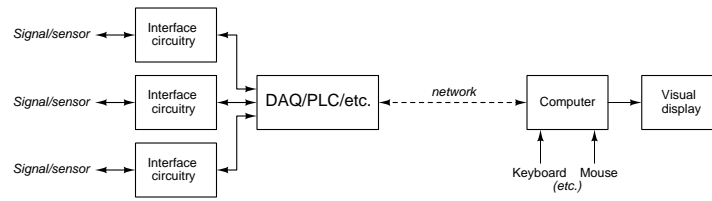
13 Experiment – data acquisition option

NAME: _____

DUE DATE: _____

Design and build a Supervisory Control and Data Acquisition (SCADA) system implementing telemetry (i.e. remote measurement) of electronic signals, using a DAQ, PLC, microcontroller, or some other digital peripheral and a personal computer with a digital user interface (UI) of your own making for displaying this data. Pre-existing data acquisition software and/or manufactured HMI hardware is not allowed for this UI. Communications between the computer and the DAQ shall occur over some form of digital serial network (e.g. RS-485, Ethernet, digital radio). Examples include remote sensing of sensor signals, radio signals, power system voltages and currents, etc.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record a user interface (UI) of your own remotely displaying at least one DAQ/PLC input signal via a digital network.

Instructor certifies – Demonstrate and record a user interface (UI) of your own making displaying multiple DAQ/PLC input signals via a digital network.

Instructor certifies – Demonstrate and record a user interface (UI) of your own exerting manual control over a DAQ/PLC output signal via a digital network.

Instructor certifies – Demonstrate and record your user interface (UI) program running a “loop” for continual operation.

Instructor certifies – Demonstrate automatic control by the DAQ/PLC where its output value(s) depend on input conditions.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Sensor/signal values accurately displayed on UI in practical units of measurement
- UI program runs continuously and does not have to be re-started for every new measurement
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

file we_3019

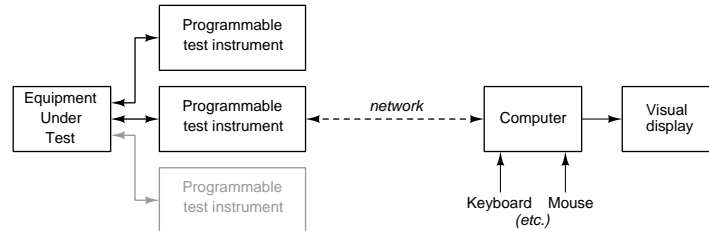
13 Experiment – automated test option

NAME: _____

DUE DATE: _____

Design and build an automated testing system using a personal computer to sequence operations on programmable test instruments such as power supplies, digital multimeters, oscilloscopes, signal generators, and/or data acquisition (DAQ) units. The personal computer must be programmed in a text-based language such as Python or C, collating the results of the test into comma-separated variable (CSV) format suitable for plotting in a spreadsheet. Your choice of Equipment Under Test (EUT) is arbitrary, but must be a circuit liable to error and/or miscalibration. A simple opamp amplifier circuit would be ideal for this.

Block diagram:



Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate and record a simple program communicating with one test instrument.

Instructor certifies – Demonstrate and record a simple program communicating with another test instrument.

Instructor certifies – Demonstrate and record a simple program coordinating the actions of two or more test instruments networked with the same personal computer.

Instructor certifies – Demonstrate and record a *passing* automated test on the EUT.

Instructor certifies – Demonstrate and record a *failing* automated test on the EUT.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Source code is clearly commented
- Program reliably identifies passing versus failing EUTs
- Program implements best-practices for automated testing (e.g. ample settling time, powering down at conclusion, etc.)
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

13 Experiment – metrology option

NAME: _____

DUE DATE: _____

Design and build an experimental metrology system or component. This could be a reference standard (e.g. precision voltage reference, frequency reference), a piece of test equipment (e.g. null detector, Kelvin-Varley voltage divider, electrometer), or anything else needed for high-accuracy electrical measurement. A series of articles written for *Electronics Now* in 1996 by Conrad Hoffman entitled “Mini Metrology Lab” gives excellent ideas for such an experimental system.

Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate proof-of-concept prototype for the metrology device/system chosen.

Instructor certifies – Demonstrate the *null-balance voltage measurement* technique to precisely compare one voltage against another, or to standardize a voltage-measuring instrument without loading the reference source.

Instructor certifies – Demonstrate the *Wheatstone bridge* technique to precisely compare an unknown resistance against known (standard) resistances.

Instructor certifies – Demonstrate testing of the device for *drift* over time, temperature changes, or any other significant error-inducing factors using trusted standards such as the lab’s Fluke metrology equipment or our own precision voltage reference.

Instructor certifies – Demonstrate collection and organization of test data in a spreadsheet or other mathematical tool (e.g. Python program) for statistical analysis including mean (average), median, and standard deviation.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Device/system fulfills its intended function
- Precautionary test protocols applied throughout, as though the circuit harbored dangerous voltage levels
- Device/system tests accurately against trusted metrology standards in lab
- A simple user’s guide instructs how to use the device/system
- A single *Experiment Journal* document containing all information about the system
- Schematic diagram challenge

13 Experiment – software-defined radio option

NAME: _____

DUE DATE: _____

Design and build an experimental software-defined radio (SDR) system, where a circuit digitizes radio signals for a computer to process, and software interprets these signals properly. An excellent and inexpensive SDR hardware unit is the RTL-SDR available from several online retailers. SDR software options include SDR# which is a ready-to-use AM/FM receiver application, as well as the free and open-source GNU Radio Companion which allows you to create digital-signal processing (DSP) systems by manipulating block-diagram components rather than writing text-based code.

Instructor consultation – Discuss general plan, components available, safety considerations, etc. Document this and all other information about the project in one “Experiment Journal” electronic document, and be sure to record *all* data in this same document, even from mistakes!

Stand-alone demonstrations (may be completed in any order; –5% per re-try, each):

Instructor certifies – Demonstrate proof-of-concept by playing a local radio station through the SDR hardware. Again, the RTL-SDR receiver unit is highly recommended for this purpose, as is ready-to-use SDR# software.

Instructor certifies – Demonstrate *decimation* applied to a digitized signal using your own DSP signal chain.

Instructor certifies – Demonstrate *mixing* applied to two digitized signals using your own DSP signal chain.

Instructor certifies – Demonstrate *digital filtering* applied to a digitized signal using your own DSP signal chain.

Instructor certifies – Identify local public radio frequencies in your area used for such purposes as fire, police, etc. using public radio-frequency databases available online.

Instructor certifies – Demonstrate reception of an AM signal such as the WWV time broadcasts from the NIST at 5 MHz, 10 MHz, 15 MHz, etc. using your own DSP signal chain.

Complete system demonstration (must be completed last, in a single session; –10% per re-try):

Instructor certifies

- Working radio receiver system is able to properly demodulate and play local broadcast radio signals, complete with tuning and audio volume controls
- Digital signal processing chain used for decoding the SDR hardware’s captured radio signal is customized/written by you
- A simple user’s guide instructs how to use the SDR receiver system
- A single *Experiment Journal* document containing all information about the system
- Explain in detail the block diagram documenting the SDR hardware receiver unit used in your system

14 Assessment

NAME: _____

DUE DATE: _____

Design, build, and demonstrate a potentiometer-adjusted network with low and high limits, so that full sweep on the potentiometer (i.e. from full counter-clockwise to full clockwise) produces the results arbitrarily specified by the instructor. Additionally, you will write a text-based computer program (e.g. C, C++, Python) modeling the network based on user-specified potentiometer wiper position setting (entered as a number between 0 and 100 percent).

This exercise tests your ability to properly design and build a network using a potentiometer in conjunction with fixed-value resistors in series-parallel fashion to achieve a desired results, use test equipment to measure this range, properly organize all electrical connections, and write a computer algorithm to predict the network's behavior.

The following components and materials will be available to you: assortment of **fixed resistors** ; **potentiometers** ; **DC power sources** ; **signal generators** ; **oscilloscopes**. You must provide your own tools, a digital multimeter (DMM), a computer with programming software installed, and your Development Board as well as a copy of this page for your instructor to mark design criteria.

Variable resistance network option:

Resistance @ full CCW (instructor chooses) = _____ (Ohms)

Resistance @ full CW (instructor chooses) = _____ (Ohms)

Variable voltage network option:

Voltage @ full CCW (instructor chooses) = _____ (Volts)

Voltage @ full CW (instructor chooses) = _____ (Volts)

Source voltage (instructor chooses) = _____ (Volts)

Variable cutoff frequency option:

Filter type (instructor chooses one) = _____ Low-Pass _____ High-pass

Cutoff frequency @ full CCW (instructor chooses) = _____ (Hz)

Cutoff frequency @ full CW (instructor chooses) = _____ (Hz)

Be sure to measure your potentiometer's end-to-end resistance before performing any calculations or modeling, as this value is typically imprecise (e.g. a "10k" potentiometer may read substantially more or less than 10000 Ohms from end-to-end!).

SEQUENCE: (1) Instructor chooses criteria and verifies all components are disconnected from each other; (2) You write and test the modeling program; (3) Instructor observes your program's output while you correctly explain how the source code works; (4) You build and test your circuit (using a multimeter) without any power sources at all; (5) Instructor observes circuit energizing for the very first time; (6) You prove to the instructor that the circuit performs as predicted by your program, using test equipment as necessary.

Quantitative results must fall within the tolerance of your circuit's components to be considered correct. For students working remotely rather than in-person, the entire exercise will take place via videoconference to permit instructor observation from start to finish.

Circuit design assessments are *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try requires new criteria (e.g. different circuit, different design parameters). Scoring is based on the number of attempts necessary to successfully design, build, and demonstrate a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%). Failing to follow instructions counts as an unsuccessful attempt and will require a re-try.

file we_1126

15 Assessment

NAME: _____

DUE DATE: _____

Troubleshoot a fault within a measurement/control system. A complete schematic diagram for the system will be allowed for use during the troubleshooting exercise.

- Any cable failed open
- Any cable failed shorted
- Any component failed open
- Any component failed shorted
- Any component value altered
- Any network configuration parameter altered
- Any fault in the physical system being monitored and controlled
- Any line of code altered

First, you will demonstrate that the system functions properly. Then the instructor will either set up or supervise other students setting up a random fault in that system (hidden from view) while you are out of the room. You will then have a limited amount of time to independently perform measurements and other tests while under the continuous observation of the instructor. A successful troubleshooting exercise consists of both correctly identifying the location and nature of the fault, as well as logically defending the necessity of each diagnostic step. Incorrect fault identification, unnecessary steps, and/or incorrect defense of any step will result in a failed attempt. Your only access to the faulted circuit will be via the test points, and only one unpowered test will be permitted.

If you must work remotely rather than in-person, the faulted system must be at the instructor's location while you request measurements and other diagnostic tests of the instructor via teleconferencing system (e.g. videoconference, telephone, text messaging).

Troubleshooting is *mastery-based*, meaning every one must be competently completed in order to pass the course, and you will be given multiple opportunities to re-try if you do not pass on the first attempt. Each re-try begins with another randomized fault on the same circuit. Scoring is based on the number of attempts necessary to successfully troubleshoot a circuit (e.g. 1 attempt = 100% ; 2 attempts = 80% ; 3 attempts = 60% ; 4 attempts = 40% ; 5 attempts = 20% ; 6 or more attempts = 0%).

file we 1022

16 Lab clean-up

NAME: _____

This list represents all of the major work-items that must be done at every semester's end to prepare the lab space for the upcoming semester. Each student will have at least one task assigned to them.

Non-technical tasks

- Thoroughly clean whiteboard(s) and all table/workbench surfaces
- Vacuum-clean the floor of all debris after picking any and all larger pieces
- Organize all wires, cables, power cords, and test leads neatly into their storage locations
- Vacuum-clean the exterior and interior of all electrical enclosures and cabinets
- Move test equipment to their proper places and clean their outer surfaces
- Note any depleted bins (electronic components, threaded fasteners, cables, etc.)
 - Check boxes and spools of components to see if depleted bins may be re-filled from these
 - Report to instructor for re-ordering in preparation for next semester
- Note any depleted PCBs (e.g. fuseholder PCBs, proto PCBs, etc.)
- Power up each lab PC to check for routine software updates, then power down for the break

Technical tasks

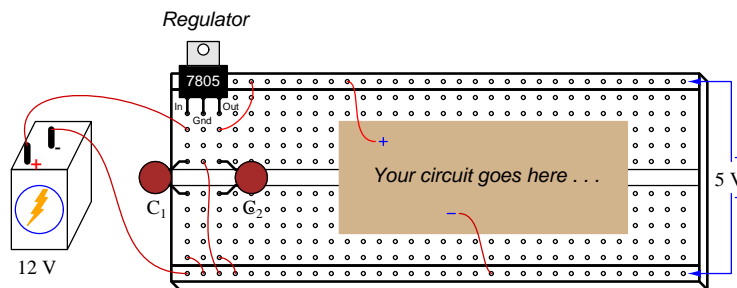
- Check fastener storage bins to ensure none are misplaced
- Check resistor storage bins to ensure none are misplaced
- Check fuse storage bins to ensure none are misplaced
- Check inductor/transformer storage bins to ensure none are misplaced
- Check capacitor storage bins to ensure none are misplaced
- Check semiconductor device storage bins to ensure none are misplaced
- Test power supplies and benchtop multimeters for basic functionality (e.g. all *power supply* voltage adjustments functional, current limits functional, voltage/current meters functional ; all *multimeter* all voltage ranges functional, all current ranges functional, overcurrent fuse good)
- Test oscilloscopes and signal generators for basic functionality (e.g. all *oscilloscope* channels functional, all vertical sensitivity settings functional, all timebase settings functional, triggering functions properly ; all *signal generator* waveshapes functional, magnitude and frequency adjustments functional)
- Test and clean all soldering stations (e.g. clean/replace porous and brass-wool cleaning pads, check tips for wear, ensure correct temperature settings and that the tip solders well)
- Test all lab power system (e.g. solar power grid, hand-crank generator) circuit breakers and fuses
- Test all special lab systems for basic functionality ; ensure schematic diagrams are in place
 - Digital clock, window crane system, window sensors, precision voltage reference
 - Ping all installed Ethernet addresses to ensure devices respond (e.g. PLC processors)

General Circuit Design Tips

When designing and constructing circuits for experimental and prototyping purposes, the following tips are recommended for success:

- **Sketch a schematic diagram before constructing anything.** You need to have a clear understanding of what it is you intend to build before you begin building, in order to avoid major errors and hazards, and planning your build in schematic form is an excellent way to do that. Having a clear diagram in hand also aids others who you might wish to help you if things don't work as planned.
- **Build and test in stages.** If you try to build the entire system before testing it, you will very likely encounter multiple errors which will be more time-consuming to diagnose than if you took the time to build and test each portion of your circuit before building and testing the next portion.
- **Choose resistor values between 1,000 and 100,000 Ohms** unless there is some compelling design rationale for using a smaller or larger values. Reactance values within AC circuits should also fall within these same limits. Circuits built with low-value resistors tend to dissipate a lot of power when energized by constant-voltage sources, while circuits built with high-value resistors tend to exhibit “signal sag” when connected to loads and/or test equipment.
- **Use decoupling capacitors** connected in parallel with the DC power pins of every integrated circuit, to stabilize DC voltage for reliable operation. This is especially critical for high-speed digital circuits and sensitive analog circuits, where variations in DC supply voltage may compromise signal integrity. 1 μF ceramic capacitors work well for this purpose, and should be located as close to each IC's power supply terminals as possible.
- **Diversify your learning experience** by using different types of test equipment (e.g. DMMs, VOMs, oscilloscopes), different types of construction techniques (e.g. solderless breadboards, soldered connections, terminal blocks), and different types of power sources. Remember, the reason you are in this course is to *learn*, not just to complete assignments!

When using sources of energy other than laboratory-quality power supplies, you may need to stabilize source voltage to ensure reliable circuit function. This is especially true when using chemical batteries, solar panels, and other electrical sources known for varying voltage output. A simple integrated circuit called a *three-terminal fixed voltage regulator* takes in power at some voltage larger than what your circuit needs, and dissipatively reduces the voltage level to a fixed value determined by the part number of the regulator IC. The popular LM78xx series of voltage regulators is recommended, where the last digits represent the fixed output voltage (e.g. 7805 = 5 Volts, 7812 = 12 Volts, etc.). An illustration showing how such a regulator might be installed in a solderless breadboard for general experiment/prototype use is shown here:



Decoupling capacitors C_1 and C_2 help stabilize the regulated voltage if your circuit's load current happens to pulse rather than be steady over time. Consult the regulator IC's datasheet for pin designations, recommended capacitor sizes, and also for general maximum voltage and current ratings.

[file eet_tips](#)

General Troubleshooting Advice

All electronic circuit faults fall into at least one of these categories:

- **Connection fault** – the components are not properly connected together.
- **Design flaw** – the circuit cannot work because something about it is incorrectly designed.
- **Lack of power/signal or poor quality** – the power and/or signal source is “dead” or “noisy”
- **Component fault** – one or more components is faulty.
- **Test equipment** – either the test equipment itself is faulty, or is not being used appropriately.

Of these categories, the one causing more problems for students initially learning about circuits than all the others is the first: *connection fault*. This is because the ability to translate an idea and/or a schematic diagram into a physical circuit is a skill requiring time to develop. Many such problems may be avoided by (1) drawing a complete schematic of what you intend to build before you build it, (2) marking that schematic to show which connections have been made and which are left to make as you are wiring it, and (3) using an ohmmeter (not your eyes!) to verify that every pair of points which should be connected are connected and that no points which should be electrically distinct from each other are in fact electrically common.

Troubleshooting strategies

- **Verify the symptom(s)** – Always check to see that the symptom(s) match what you’ve been told by others. Even if the symptoms were correctly reported, you may notice additional (unreported) symptoms helpful in identifying the fault.
- **Use test equipment rather than your eyes to find problems** – your multimeter (and other tools) will show you things your eyes cannot see, and this will build habits and skills invaluable in situations where visual inspection is impossible.
- **Verify good power quality** – Is the source voltage within specifications, and relatively free of “ripple” and other noise?
- **Check signals at component terminals** – Use an oscilloscope or multimeter to check for proper signals at each of the component pins, to see if each one matches your expectations. An important check, especially for integrated circuits, is whether the measured output signal(s) are appropriate for the measured input signal(s).
- **Simplify the system** – If possible, re-configure the circuit to be as simple as possible, because complexity makes faults harder to find.
- **Take more and different measurements to get un-stuck** – if the source of trouble is still not apparent, take measurements in places you haven’t tried yet to obtain new data. Also, use different test instruments that will show you other facets of the signals, for example try using an oscilloscope to test a signal if you’ve only been using a multimeter since an oscilloscope will reveal things a multimeter cannot.
- **Swap identical components** – If particular a component is suspected of being faulty, and you are able to swap another (identical) component for it, do so to see whether or not the problem moves with the old component. If so, that component is to blame; if not, the problem lies elsewhere.
- **Always look for Root Cause(s)** – don’t declare success simply by finding the proximate (i.e. the most direct) cause, but continue your search to find what design flaw, circumstance, or other distal cause led to it.