IETTI-223 – Advanced Electronics Theory (Semester 4 THEORY)

NAME: _____ Last update 7 August 2026

Session	Topic	Journal	P.S.	Comments
Session 01	Intro to the Career			
Session 02	C coding – bitwise operations			
Session 03	Digital computing circuits			
Session 04	Digital memory			
Session 05	Finite-state machines			
Session 06	Intro to Microprocessors (I)			
Session 07	Intro to Microprocessors (II)			
Session 08	Intro to Microprocessors (III)			
Session 09	Programmable logic ICs			
Session 10	C coding – pointers and arrays			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 13	Serial data communication (I)			
Session 14	Serial data communication (II)			
Session 15	Transmission lines			
Session 16	RS-232/422/485 serial networks			
Session 17	SPI and I2C serial networks			
Session 18	Ethernet networks			
Session 19	IP/TCP/UDP protocols			
Session 20	Internet-based systems			
Session 21	Modbus networks			
Session 22	Optical communication			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 25	Intro to RF			
Session 26	Frequency-shifting			
Session 27	Smith charts (I)			
Session 28	Vector network analyzers			
Session 29	Smith charts (II)			
Session 30	s-domain analysis (I)			
Session 31	s-domain analysis (II)			
Session 32	Transfer functions (I)			
Session 33	Transfer functions (II)			
Session 34	Transfer functions (III)			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 37	Sensors			
Session 38	Opamp review (I)			
Session 39	Opamp review (II)			
Session 40	Analog-digital conversion			
Session 41	Signal referencing and scaling			
Session 42	Opamp applications			
Session 43	Data acquisition			
Session 44	Multi-pole filter circuits			
Session 45	Filters and transfer functions			
Session 46	Active filter circuits			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 49	Metrology fundamentals			
Session 50	Electrical metrology standards			
Session 51	DC electrical metrology			
Session 52	Frequency and time			
Session 53	Phase-locked loops			
Session 54	Automated testing			
Session 55	Process control systems			
Session 56	Analog instrument signals			
Session 57	Control system troubleshooting			
Session 58	Review day			
Session 59	ORAL PRESENTATIONS			
Session 60	EXAM			

Essential information about this course:

- The purpose of this entire program is to empower you with knowledge, skill, and habits for your chosen craft, and doing your own work is absolutely necessary to that end. Relying on other people and/or artificial intelligence (AI) to read, write, design, plan, analyze, diagnose, or in any other way *think for you* defeats this purpose and will be considered plagiarism. Appropriate help always sharpens and never replaces a person's own ability to think and to do. Bear this in mind both when seeking help and when assisting classmates!
- The difference between *education* and *training* is learning to reason from principles versus following instructions. In this course you will learn principles of circuits and sharpen your reasoning skills by *reading* extensively, *writing* your thoughts, and *dialoguing* with the instructor(s) and with classmates rather than consuming lectures. Preparatory work precedes each class session.
- Learning trustworthy and responsible habits is just as important to your career as developing knowledge and skill, and responsibility develops only with application. You bear responsibility in this course to manage your time, clearly and promptly communicate, and set priorities. Your instructor(s) will provide ample guidance and feedback.
- Assignments and assessments are just means to an end, and that end is learning. Similarly, grades, certificates, and degrees are just symbols of that same end. Prioritize *learning* and you will do well on your assignments and assessments, and your grades will reflect that. If you instead treat activity completion as the goal and grades as a prize, you'll not only sacrifice learning but also struggle to complete the assignments and obtain the grades you desire. Don't confuse the means versus the end; don't chase symbols in lieu of what they're supposed to represent.
- Half of your course grade comes from "oral presentations" designed to mimic technical job interviews. The other half comes from written "mastery exams" requiring correct answers on every question to pass, with multiple re-tries allowed on different exam versions. Answers must be accurate *and* well-reasoned from appropriate principles to count as correct.
- Late arrival and/or unpreparedness for theory sessions will result in point deductions. Demonstrations of unprofessional behavior will trigger private meetings with your instructor(s).
- You should budget a minimum of 12 hours per week for this course, approximately 4 hours in-class and at least 8 hours out-of-class preparation.
- Successful students (1) prioritize their study time, (2) test themselves on upcoming oral presentation and written exam topics, (3) and master principles rather than memorize procedures.

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.

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EET Program Learning Outcomes

(1) **COMMUNICATION and TEAMWORK** – Accurately communicate ideas across a variety of media (oral, written, graphical) to both technical and non-technical audiences; Function effectively as a member of a technical team.

(2) **SELF-MANAGEMENT** – Arrive on time and prepared; Work diligently until the job is done; Budget resources appropriately to achieve objectives.

(3) **SAFE WORK HABITS** – Comply with relevant national, state, local, and college safety regulations when designing, prototyping, building, and testing systems.

(4) **ANALYSIS and DIAGNOSIS** – Select and apply appropriate principles and techniques for both qualitative and quantitative circuit analysis; Devise and execute appropriate tests to evaluate electronic system performance; Identify root causes of electronic system malfunctions.

(5) **PROBLEM-SOLVING** – Devise and implement solutions for technical problems appropriate to the discipline.

(6) **DOCUMENTATION** – Interpret and create technical documents (e.g. electronic schematic diagrams, block diagrams, graphs, reports) relevant to the discipline.

(7) **INDEPENDENT LEARNING** – Select and research information sources to learn new principles, technologies, and/or techniques.

Course description

This course introduces microprocessor systems – including computer programming in both assembly language and C – and also explores serial data communication, advanced RF topics (e.g. modulation, mixers, Smith charts, VNAs), industrial signal conditioning, and industrial control systems. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

Course learning outcomes

- Predict the performance of programmable circuits, serial data networks, complex RF circuits, analog signal conditioning circuits, and automated electronic systems given schematic diagrams, component values, and other circuit parameters. (Addresses Program Learning Outcomes 4, 6)
- Write simple code to instruct a microprocessor or microcontroller to perform stated tasks. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple digital memory circuits, serial data communication circuits, radio circuits, signal-conditioning circuits, and automation systems to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to microprocessors, data communication, RF modulation, signal conditioning, and automation systems as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in microprocessor or microcontroller peripheral circuits, data communication circuits, radio circuits, signal processing circuits, and control systems given schematic diagrams and reported symptoms. (Addresses Program Learning Outcomes 5, 6)
- Summarize physical laws and concepts related to the aforementioned circuit types, acquired from technical literature, and clearly present them in both written (journal) and oral formats. (Addresses Program Learning Outcomes 1, 6, 7)

Required Tools, Supplies, and Software

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

Semester 1 = IETTI-101 (Theory), 103 (Experiments), and 102 (Projects)
Semester 2 = IETTI-104 (Theory), 112 (Experiments), and 105 (Projects)
Semester 3 = IETTI-222 (Theory), 221 (Experiments), and 220 (Projects)
Semester 4 = IETTI-223 (Theory), 225 (Experiments), and 236 (Projects)

Tool, Supply, or Software installation	Thy 101	Exp 103	Prj 102	Thy 104	Exp 112	Prj 105	Thy 222	Exp 221	Prj 220	Thy 223	Exp 225	Prj 236
$5 mechanical pencil and eraser	X	X	X	X	X	X	X	X	X	X	X	X
$5 permanent marker			X			X			X			X
$25 scientific calculator	X	X	X	X	X	X	X	X	X	X	X	X
$300 personal computer	X	X	X	X	X	X	X	X	X	X	X	X
$10 USB "flash" drive	X	X	X	X	X	X	X	X	X	X	X	X
$50-$400 digital multimeter		X	X		X	X		X	X		X	X
$190 USB-based oscilloscope		X	X		X	X		X	X		X	X
$10 solderless breadboard (e.g. Busboard BB830)		X	X		X	X		X	X		X	X
$25 grounding wrist strap		X	X		X	X		X	X		X	X
$10 slotted screwdrivers (1/8",1/4")		X	X		X	X		X	X		X	X
$10 Phillips screwdrivers (#1,#2)		X	X		X	X		X	X		X	X
$10 jeweler's screwdriver set		X	X		X	X		X	X		X	X
$10 wire strippers, 18-24 AWG		X	X		X	X		X	X		X	X
$10 needle-nose pliers		X	X		X	X		X	X		X	X
$20 diagonal wire cutters		X	X		X	X		X	X		X	X
$10 metal rule (inches & mm)		X	X		X	X		X	X		X	X
$15 utility knife			X			X			X			X
$10 alligator-clip jumper wires (package of at least ten)		X	X		X	X		X	X		X	X
$15 batteries: 6 Volt and 9 Volt		X	X		X	X		X	X		X	X
$15 illuminated jeweler's loupe		X	X		X	X		X	X		X	X
$10 safety glasses			X		X	X			X			X
$25-$100 soldering iron (pencil-tip), 30 Watts or less			X		X	X			X			X
$15 tube/spool of rosin-core solder			X		X	X			X			X
$90 PLC I/O card		X			X			X			X	
$15 microcontroller and software								X			X	X
$0 software: Python interpreter	X			X			X			X	X	X
$0 software: schematic editor		X	X		X	X		X	X		X	X
$0 software: text editor		X			X			X			X	
$0 software: `NGSPICE` circuit sim.		X			X			X			X	
$0 software: `WSL`	X	X		X	X		X	X			X	
$0 software: `tshoot` fault sim.	X	X		X	X			X			X	
$0 software: `sp.c` simulator	X			X			X					
$0 software: packet-sniffing software										X	X	X
$0 archive: EETREF collection	X			X			X			X		

Required Tools, Supplies, and Software

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

Personal computer – we use computers every day for applications such as teleconferencing software (e.g. Zoom), document reading and creation, coding, and circuit simulation. Having your own portable computer is therefore essential. Most operating systems, hard drive capacities, RAM memory sizes, and screen sizes are appropriate, but your computer must have a keyboard and mouse (i.e. no tablets). Avoid ChromeBooks. Useful but non-essential features include an RJ-45 Ethernet port and multiple USB ports.

Multimeter – this is your first and most important electronic test instrument. At minimum it must measure DC and AC voltage, DC and AC current (milliAmpere range), resistance, and "diode check" voltage drop. Cost is a strong function of accuracy, additional features, frequency range, and safety ("Category" ratings for over-voltage exposure). The Fluke model 17B+ is an excellent choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. The best *minimal-cost* multimeter I've found is the model DT-830B which sells for less than $20, with the test leads being the weakest component (but easily upgraded).

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

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

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

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

Required Tools, Supplies, and Software

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

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

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

Text editor – this is used to create plain-text files, kind of like a word processor but lacking formatting features such as typeface, font size, etc. `Notepad++` and Microsoft's `VS Code` are both excellent options.

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

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

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

tshoot – this is a specialized circuit-simulator program that inserts faults into circuits and tests your ability to locate them. The download consists of one "tar" file you unpack and compile using the following three commands within a Unix-type operating system or within `WSL`. The fourth command runs the application:

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

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

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

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

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

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

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Grading standards for Theory 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:

- Oral presentation scores = 50%
- Written exam scores = 50% (Note: all exams are mastery-based, which means they must be eventually passed with correct answers for every question in order to pass the course)
- Missing Theory Journal entry = −1% per session
- Unattempted problem(s) = −1% per session

All theory sessions are based on an "inverted" model of instruction rather than lecture. Instead of passively listening to the instructor explain new concepts, students independently explore those new concepts outside of class, journal their thoughts on these new concepts, and then spend the entire class time discussing those concepts and solving practical problems. This instructional model has proven far more effective than lecture, principally because student engagement is mandatory and not optional. Inverted instruction also reveals to the instructor *how each student thinks*, enhancing the instructor's ability to coach students on sound reasoning. It also greatly minimizes the classroom time necessary to achieve the same learning outcomes (approximately *half* the time as required by lecture to achieve the same results).

You must keep a Theory Journal, written entirely in your own words, as a tool to document your learning and to sharpen your understanding of the concepts. Any format is acceptable so long as relevant portions of it may be electronically shared during class sessions. You are strongly encouraged to log all of your work in this Theory Journal, including assigned problems, practice problems, etc.

Penalties apply to any lack of documented effort for theory sessions: a −1% deduction to your course grade will be levied if you arrive to class late or without a Theory Journal entry for that session's assigned reading, and a separate −1% deduction will occur if any assigned problem is unattempted. Note that your journal entries and solution attempts need not be error-free and that misconceptions and mistakes are expected.

If you must be late or absent for a theory session, submitting your work in electronic form (e.g. email attachment) prior to the scheduled time is acceptable for full credit:

- For preparation, submission of your Theory Journal entry before the scheduled start time of that theory session will count as full credit. If you know you will be late to class, sending the journal entry before the start of class will excuse the tardiness.
- For problem-solving, *correctly* answering all assigned problems in order to ensure you understand the day's topic. Partial credit will be awarded for this based on how many of the answers are correct versus incorrect.

Absence during a scheduled oral presentation or a scheduled written exam will result in a 0% score for that assessment, except in the case of a *documented emergency*. In such emergency cases, written exams may be taken at some later time for full credit, and oral presentations may also be completed at a later date for full credit. Taking an exam in advance of the scheduled date is always allowed. During any assessment you are free to ask the instructor for clarification, but the instructor will not help you solve any problem nor will confirm if an answer is correct prior to its submission for scoring. Only answers supported by proper principles and sound reasoning will be counted as correct – "right" answers based on guessing or luck will not.

A failing (F) grade will be earned for the entire course if any written exam is not passed (i.e. *all* answers correct) on or before the deadline date, or for any behavior that would result in being fired from a job, including false testimony (lying), cheating on any assignment or assessment, plagiarism (relying on another's work instead of your own, including artificial intelligence), willful violation of a safety policy, habitual tardiness or absenteeism, theft, harassment, sabotage, destruction of property, or intoxication.

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Instructor guidelines

The design and structure of this course is quite unconventional, but proven to deliver robust outcomes. In addition to imparting technical knowledge and skill related to the subjects of electricity and electronics, this course seeks to also teach students how to think clearly and critically about these subjects. To this end, students first encounter new subject matter through independent reading rather than by lecture, their time in class spent actively sharing, debating, and solving problems rather than passively listening. Your job as the instructor is to hold students accountable for good-faith preparation, and to ensure they *reason* from basic principles rather than merely recall facts and follow procedures.

Every class session should begin with a review of students' assigned reading. Have students share what they learned by presentation of their written journal entries and orally by speaking to the class as a whole. Good-faith effort is the standard of acceptance here, with errors and misconceptions expected since this material is new to them. At minimum every student should be able to show written summaries of the major concept(s) *in their own words* with any verbatim citations indicated as such. Intelligent questions are always welcome journal entries! Maintaining a thoughtful journal and presenting orally in class are non-negotiable requirements, as the skills of clear writing and public speaking do not grow any other way than by exercising them, and also because these activities help foster critical thinking. *You should also write your own journal if teaching the course for the first time*, both to set a good example for students as well as better understanding their learning experience.

Students must also be held accountable for attempting to solve each and every problem assigned to them in advance of their arrival. Again, the standard of acceptance is good-faith effort, with errors and misconceptions expected. Every student is capable of applying *at least one* problem-solving strategy to every problem (e.g. identifying relevant principles, sketching a diagram to visualize the problem, simplifying the problem, converting it from quantitative to qualitative or vice-versa, trying limiting cases, etc.). A blank page is unacceptable. You should demonstrate general problem-solving strategies every day, encouraging students to record those strategies in their journals, so that no one can ever claim "I don't know where to begin" when faced with a new problem.

Exactly how you hold students accountable for their preparatory work is left up to your professional discretion, so long as they indeed do the work. Be flexible and open-minded in your methods, but firm in holding students accountable to *reading*, *writing*, *speaking*, and *reasoning*.

Class sessions should feature students talking more than you. Your job is to probe their understanding with questions, and to guide their thinking without thinking for them. Socratic dialogue is a good model to follow: question students' responses whether correct or incorrect, asking them to provide reasons for their answers. The most important question you can ask is, "Why?" Give students enough time to carefully consider the question when answering. Silent problem-solving sessions are good, too, to give students room to think independently while you offer individual assistance. Students should update their journals with any insights gained during class time, treating it as a living document of their learning.

Suggested learning outcomes and methods to measure student learning appear in the "Recommendations for instructors" section of each module's Introduction chapter. These may be used to help design a course of study, and/or as focal points for classroom discussions around that module's tutorial(s).

When students ask for help, *don't solve the problem for them.* Instead, suggest appropriate problem-solving strategies and observe them doing the work. When students ask you to review a concept they've studied previously, point them to a trusted source of information (e.g. their learning modules) and offer to discuss what they read together. Also, don't be too quick to confirm their solutions – instead, show them appropriate ways to validate the correctness of their own work (e.g. working the problem backwards, verifying by computer simulation, etc.). Always remember that you are preparing students to be *independent* learners and problem-solvers, as they will not have your assistance after they complete your course. Far too many students focus on the myopic goals of completing assignments, achieving good grades, passing a course, and earning a degree to the detriment of long-term value found in professional knowledge, skill, and habits. *Your job as the instructor is to draw students' attention toward what matters most.*

Theory session 01

Source text – *Career Guide* learning module
URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the "Growing Your Career" chapter of the *Career Guide* document
- Read, reflect, and update your Theory Journal on the "Managing Finances" chapter of the *Career Guide* document

Source text – *Introduction to Python Language Programming* learning module
URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_python.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read the first few sections of the "Case Tutorial" chapter of the *Python* document
- Try running your own Python program(s)!

Complete the following *during* the scheduled session:

- Discuss what you read in the *Career Guide*
- Discuss philosophy and design of the program:
  → Focus on building human capital: technical knowledge/skill *and* professional habits
  → Active learning: reading, writing, dialoguing, budgeting time and resources
  → Frequent feedback and clear deliverables built into every course
  → Any behavior that would get you fired from a job will result in a failing grade in any course here
- Discuss time commitment: *a minimum of 3 hours per week per enrolled credit is necessary for success! If you're taking a full load of courses, plan to be here all day every day!*
- [Optional] – sign FERPA release forms
- Experiment with Python programming together as a class
- [Recommended] – *be available to give advice to the new students this semester!*

`Important resources:`

- `https://ibiblio.org/kuphaldt/socratic/model`, the *Modular Electronics Learning Project* web page containing all course documents, tutorials, and problem sets you will need in these courses
- `https://ibiblio.org/kuphaldt/socratic/model/calendar.html`, our semester calendar showing dates for theory sessions, special events, and all-lab project sessions
- `https://ibiblio.org/kuphaldt/socratic/model/daily_schedule.pdf`, showing Monday-Friday class schedule
- "Required Tools, Supplies, and Software" page (in this document)
- EETREF – a collection of digital documents often referenced in homework assignments, available as a folder on the Desktop of every computer in the lab, or directly from the instructor if you provide a USB flash drive for copying

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Theory session 02

Source text – *Introduction to C Language Programming* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Bitwise operators
- During today's theory session, the instructor will demonstrate ways to write an effective Theory Journal entry, using today's reading assignments as the source text. This exercise will be participatory, the instructor soliciting input from each of you as to what might go in this Theory Journal entry.
  → One sentence written for every paragraph read is a good default ratio to follow
  → Any confusing or unclear points should be noted by questions in your Theory Journal
  → Explore how to screen-capture and annotate images from the text for inclusion in the Theory Journal, especially if using markup languages such as `Markdown`
  → Explore methods of speech-to-text capture for those who do not type fast
  → We will time how long it takes to write a complete Theory Journal entry, determining an average number of minutes per page of text
  → Plan on organizing your Theory Journal by topic, not by session number – if using a plain-text format such as Markdown requiring little storage space, plan on maintaining a single file with all your entries as this will make it much easier to search!
  → Devote a separate section of your Theory Journal as a "Conceptual Toolbox" where you will accumulate all important concepts, laws, principles, and problem-solving strategies you learn about electric circuits, and where you may easily find it when needed. We will use this "toolbox" on a daily basis to solve problems!
- Complete "Driving microcontroller output bits" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Bitwise operation practice" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Bit-rotate program" in the Conceptual Reasoning section of the Questions chapter.

NOTE: there are many examples of code in this lesson. A recommended strategy for learning coding is to run examples given to you to verify how they work, then modify those examples and observe the effects of your changes.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0245

Theory session 03

Source text – *Digital Computing Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Simple four-bit ALU section of the Derivations and Technical References chapter.
- Read, reflect, and update your Theory Journal on the Binary adder circuits section of the Derivations and Technical References chapter.
- Complete "74181 ALU" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Signed binary addition" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Rotary encoder" in the Diagnostic Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language demonstrating the effects of *overflow* with signed or unsigned integer numbers.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0049

Theory session 04

Source text – *Digital Memory* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Doubling data width" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Doubling address width" in the Quantitative Reasoning section of the Questions chapter.
- Locate the first edition of *The Semiconductor Memory Book* published by Texas Instruments in 1975, read the datasheet for the model TMS 4033 JL/NL static RAM chip, and answer the following questions:
  - → Identify the memory capacity and organization (address width, data width) for this memory IC
  - → Explain the elements shown in the functional block diagram on page 50 of the book
  - → Comment on the timing diagrams shown on page 52 – what do they signify?
  - → On which terminal(s) is data written to this memory IC, and on which terminal(s) is data read from it?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples showing both data expansion and address expansion using multiple memory ICs. I *strongly recommend* you examine these circuit diagrams if the concept of address expansion and data expansion is less than clear after reading the Tutorial.
- Animation of 16 × 8 ROM section of the Animations chapter.

  file wt_0057

Theory session 05

Source text – *Finite State Machines* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read the Modeling a simple finite state machine using C++ section of the Programming References chapter, then alter this program to generate a finite-state machine (FSM) sequence of your own choosing.
- Complete "Generating repeated values" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Prime sequence counter" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of failed data lines" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0128

Theory session 06

Source text – *Introduction to Microprocessors* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Digital building-blocks
  → Putting it all together – the processor
- Prepare to explain to your classmates and to your instructor the sequence of operations described in the Putting it all together – the processor Tutorial section, as this gives a very detailed view of how a typical microprocessor fetches and executes instructions. *If you have questions about this, be sure to write those in your Theory Journal for quick reference during class!*
- Complete "Intel 8080 architecture" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Intel 8080 processor cycles" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Early microprocessor timing diagram" in the Conceptual Reasoning section of the Questions chapter.
- If time permits, explore two interesting projects to create functioning non-integrated processors on large printed circuit boards: the *Gigatron* and the *MOnSter 6502*. The MOnSter 6502 attempts to replicate the famous model 6502 microprocessor IC while the Gigatron is an entire computer made of logic ICs with no integrated microprocessor. The Gigatron project is open-source, and schematic diagrams for it are contained in your EETREF document collection.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0129

Theory session 07

Source text – *Introduction to Microprocessors* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → A simple computer example
- Complete "Computer circuit modifications" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Minimal Z80 computer" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Memory map determination" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0130

Theory session 08

Source text – *Introduction to Microprocessors* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Machine code and assembly language
  → Interrupts
- Read, reflect, and update your Theory Journal on the Introduction to assembly language programming section of the Derivations and Technical References chapter.
- Complete "6502 turning on LEDs" in the Quantitative Reasoning section of the Questions chapter.
- Complete "PIC 16F18346 subroutines" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Random input states" in the Diagnostic Reasoning section of the Questions chapter.

Additionally, research and be ready to present on specific details of IETTI courses within the EET program:

- Find the page in your Theory course document listing *Oral Presentations* taking place on Session 11.
- What are some of the problems you will be expected to solve during this upcoming oral presentation session?
- How are oral presentations graded?
- What are some good ways to prepare for oral presentations?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0131

Theory session 09

Source text – *Programmable Logic ICs* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the following section of the Full Tutorial chapter:
  → Hardware description languages
- Locate a datasheet for a CPLD and prepare to share the following information about it:
  → Power supply voltage limits
  → Number of I/O pins available
  → Number of macrocells
- Locate a datasheet for an FPGA and prepare to share the following information about it:
  → Power supply voltage limits
  → Number of I/O pins available
  → Number of logic elements
- Complete "Simple FPGA programming" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Explaining the meaning of code" in the Conceptual Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0277

Theory session 10

Source text – *Introduction to C Language Programming* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Pointers
  → Arrays
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Using C arrays to analyze a resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Sine look-up table" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Array-reversal program" in the Quantitative Reasoning section of the Questions chapter.

NOTE: there are many examples of code in this lesson. A recommended strategy for learning coding is to run examples given to you to verify how they work, then modify those examples and observe the effects of your changes.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0251

Theory session 11

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

You will be randomly assigned to analyze and explain one section of a single-board Intel 8080-based computer's schematic diagram (or else review concepts from your "Conceptual Toolbox" Theory Journal section), the schematic diagram found as a PDF file in the `EETREF` collection (`EETREF/Projects/SingleBoardComputers/SingleBoardComputer_8080_schematic.pdf`). No student will know which function is theirs to explain until it is their turn to present, which means all students should be prepared to explain the *entirety* of the system. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. digital numeration, logic states, CPU instruction cycles, datasheet specifications, etc.).

Note: there are a few ICs in this schematic unique to this particular single-board computer. The GAL16V8B is a *programmable array logic*, used to mimic complex combinational logic. The designer of this board employed a PAL chip to save space rather than have several other ICs (e.g. the 8212 and 8214 peripheral ICs commonly used with the 8080 microprocessor don't exist in this computer's design). Also, an entire microcontroller is also included (AT89C2051) for the sole purpose of generating a low-frequency pulse signal called a *tick*. Two ICs specifically designed by Intel to be used with the 8080 microprocessor are the 8224 and the 8228, both present in this computer's design.

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

One of the most important skills for success in these assessments is knowing how to check your work as you progress through each problem! Applying mental math and estimations along the way for each calculated result is vital for avoiding the pitfall of a wrong result compromising future answers.

file wt_0116

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Energy efficiency **AC power factor** **Resonance** **Fourier's Theorem** **RMS value**
Filter types and properties **Transformer behavior** **Properties of Wye/Delta networks**
Pulse-width modulation **Heat transfer** **Comparator behavior** **Signal imperfections**
Latch/Flip-flop types and behaviors **Shift register behavior** **Counter behavior**
Programming concepts: *(e.g. data types, math, I/O, conditionals, loops, functions, arrays, pointers)*
Amplifier gain **Transistor biasing** **Decibels** **Current mirror behavior**
Characteristic impedance **Electromagnetic waves** **Modulation**
Maxwell's equations **Antenna behavior** **RF link budgeting**
Positive vs. Negative feedback **Opamp behavior** **Differentiation vs. Integration**
AC motor behavior **Protection zones**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Section #2 – CPU clock source

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine how the clock signal source functions in this computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

◯ [20%] Identify what establishes the clock frequency for this computer
◯ [20%] Explain the significance of the *two* clock pulse signals needed by the 8080 CPU
◯ [20%] Identify which of these two clock pulse signals has a greater duty cycle
◯ [20%] Explain the significance of the $SYNC$ signal
◯ [20%] Explain the significance of the $\overline{STSTB}$ signal

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Section #3 – System memory

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine how the RAM and ROM memory works in this computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

- ◯ [20%] Identify the total address space (i.e. maximum number of possible address locations for the 8080 microprocessor)
- ◯ [20%] Sketch a *memory map* showing the RAM and ROM memories as they exist in the microprocessor's addressing range
- ◯ [20%] Identify the electrical connections responsible for the microprocessor being able to select RAM versus ROM at any given moment in time
- ◯ [20%] Identify the electrical connections responsible for the microprocessor being able to read from versus write to any memory location
- ◯ [20%] Explain what a "monitor" program does that would be stored in the ROM

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Section #4 – General-Purpose I/O (GPIO)

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine how the General-Purpose I/O functions in this computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

- ◯ [20%] Identify the specific purpose of the GPIO in this computer's design
- ◯ [20%] Identify whether the GPIO in this computer is capable of input (I) only, output (O) only, or both (I/O)
- ◯ [20%] Explain where the GPIO data bits originate from
- ◯ [20%] Explain how the GPIO is selected to access the computer's bus(es)
- ◯ [20%] Explain what would be necessary to equip this computer with a greater number of GPIO bits

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Section #5 – Port 0

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine how Port 0 functions in this computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

- ◯ [20%] Identify whether Port 0 in this computer is capable of input (I) only, output (O) only, or both (I/O)
- ◯ [20%] Explain how Port 0 is selected to access the computer's bus(es)
- ◯ [20%] Identify the specific purpose of Port 0 in this computer's design
- ◯ [20%] Explain how this specific purpose for Port 0 happens to rely on Port 1
- ◯ [20%] Propose (in general terms) what code would need to be executed in the 8080 microprocessor to utilize Port 0 for its intended purpose

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Section #6 – Ports 1 and 2

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine how Ports 1 and 2 function in this computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

- ◯ [20%] Identify whether Ports 1 and 2 in this computer are capable of input (I) only, output (O) only, or both (I/O)
- ◯ [20%] Explain how Port 1 is selected to access the computer's bus(es)
- ◯ [20%] Explain how Port 2 is selected to access the computer's bus(es)
- ◯ [20%] Identify the specific purpose of Ports 1 and 2 in this computer's design
- ◯ [20%] Propose (in general terms) what code would need to be executed in the 8080 microprocessor to utilize Ports 1 and 2 for their intended purpose

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Section #7 – Power conditioning

Examine the schematic diagram and any relevant technical sources on the 8080 microprocessor to determine the power requirements of the various ICs and how electrical power is conditioned in this particular computer. Plan on showing the relevant portion(s) of this computer's schematic diagram to your audience as you present on this topic.

`Grading`

- ◯ [20%] Identify where power enters this computer, and what type of electrical power it is (AC versus DC, approximate voltage, etc.)
- ◯ [20%] Identify the different DC voltage levels necessary for powering all the ICs in this computer
- ◯ [20%] Explain how the first of these voltage levels is conditioned
- ◯ [20%] Explain how the second of these voltage levels is conditioned
- ◯ [20%] Explain how the third of these voltage levels is conditioned

Note: full credit given only for answers that are correct and logically supported by trusted principles and sources.

Theory session 12

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Sketch wires to form a memory array from multiple RAM or ROM ICs (i.e. address or data bus expansion).
  Digital memory IC addressing, digital memory IC enabling, decoder circuits

- (Question #2) Predict the outcome of a simple assembly-language computer program.
  Basic microprocessor function, basic microcontroller function, assembly language programming concepts, binary arithmetic, bitwise logical operations, hex dump memory displays

- (Question #3) Modify a given assembly-language program to make it fulfill a specified function.
  Basic microprocessor function, basic microcontroller function, assembly language programming concepts, binary arithmetic, bitwise logical operations, hex dump memory displays

- (Question #4) Calculate voltages, currents, resistances, and/or powers in a circuit where a microcontroller interfaces with input and/or output devices.
  Properties of series and parallel networks, behaviors of sources and loads, Ohm's Law, Joule's Law, Kirchhoff's Laws, basic microcontroller function, logic levels in TTL and CMOS circuits, pull-up and pull-down resistor function, BJT function, MOSFET function, binary-hex conversion

- (Question #5) Determine possible faults in a microcontroller I/O circuit.
  Basic microcontroller function, logic function truth tables, logic levels in TTL and CMOS circuits, BJT function, MOSFET function, effects of opens vs. shorts, Kirchhoff's Laws, Ohm's Law, behaviors of sources and loads

- (Question #6 – REVIEW) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

- (Question #7 – REVIEW) Calculate voltages, currents, and/or power dissipations in a circuit containing multiple sources.
  Properties of series and parallel networks, behaviors of sources and loads, Ohm's Law, Joule's Law, Kirchhoff's Laws

- (Question #8 – REVIEW) Convert between different forms of digital numeration (e.g. binary, octal, hexadecimal, decimal).
  Signed binary integers, unsigned binary integers, octal notation, hexadecimal notation

- (Question #9 – REVIEW) Determine logic states within a combinational logic circuit.
  Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts

file wt_0115

Theory session 13

Source text – *Serial Data Communication* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Serial communication principles
  → Physical encoding of bits
  → Communication speed
  → Data frames
  → Parity
  → Frame check sequences
- Complete "Manchester encoding of a digital word" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Serial data stream decoding" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Ambiguous Manchester data stream" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Microcontroller UART communication program" in the Conceptual Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0109

Theory session 14

Source text – *Serial Data Communication* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Flow control
  → Channel arbitration
  → The OSI Reference Model
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "EIA/TIA-232 data frames of ASCII characters" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Manchester data frame with a specified bit rate" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Microcontroller UART text and number program" in the Conceptual Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0110

Theory session 15

Source text – *Transmission Lines* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read the Tutorial chapter as necessary to refresh your memory on this subject.
- Complete "TDR cable fault testing" in the Conceptual Reasoning section of the Questions chapter.
- Complete "TDR calculator program in Python" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Traveling-wave fault location on a power line" in the Diagnostic Reasoning section of the Questions chapter.

Discuss as a group your learning experience studying transmission lines again after having studied it some time in the past. Which concepts were clearer this time than during the first time you encountered this topic? Were there any concepts that made *less* sense to you this time around? Are there questions you have now that you didn't think of asking last time?

After you graduate from this program, you will enter a career where the need for continual learning never ceases. Much of your learning after graduation will be informal, driven by your own curiosity and needs. What lessons can you take from your experience today (i.e. reviewing a previously-learned concept) that might be beneficial to your self-directed learning in the future? What does today's experience tell you about how your mind embraces complex topics? What does today's experience tell you about resources available for your own self-directed education?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Animation of an open transmission line section of the Animations chapter.
- Animation of a shorted transmission line section of the Animations chapter.
- Animation of a terminated transmission line section of the Animations chapter.

  file wt_0286

Theory session 16

Source text – *EIA/TIA-232, 422, and 485 Serial Networks* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_232_422_485.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Minimalist EIA/TIA-232 system" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Terminating and bias resistors" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Networked DAQ modules" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0136

Theory session 17

Source text – *SPI Serial Networks* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "TI CC113L Value Line Receiver datasheet" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sketching SPI waveforms" in the Quantitative Reasoning section of the Questions chapter.

Source text – *Analog Engineer's Pocket Reference, Fifth Edition*, written by Art Kay and Tim Green

EET Reference collection – `EETREF/Tutorials/TI_AnalogEngineers_Pocket_Reference_slyw038c.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the I^2C bus (Inter-Integrated Circuit) section of the Texas Instruments reference document, and answer the following questions:
  - → How does I^2C differ from SPI?
  - → What are the various lines in an I^2C network named, and what is each of their functions?
  - → How are specific "slave" devices selected by the "master" device in an I^2C network?
  - → How are data frames started and ended in an I^2C network?
  - → How is a successful I^2C data transaction acknowledged by the receiving device?
  - → What factors dictate the sizing of pull-up resistors in an I^2C network?
- Locate the M24128 serial EEPROM datasheet (document DocID16892 revised September 2017, found in the `Datasheets/memory` directory of your EETREF document collection) and answer the following questions:
  - → Explain the bit sequences necessary to write one byte of data to a particular address in this memory IC.
  - → Explain the bit sequences necessary to write data to a "page" of addresses in this memory IC.
  - → Explain the bit sequences necessary to read one byte of data from a particular address in this memory IC.
  - → Explain the bit sequences necessary to read data from a *sequence* of addresses in this memory IC.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0258

Theory session 18

Source text – *Ethernet Networks* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Use `Wireshark` "packet-sniffing" software to monitor network traffic on your personal computer, and then identify Ethernet frames for some of the captured data.
  → Specifically, identify the different data fields within each Ethernet frame (e.g. source address, destination address, etc.)
- Complete "Arbitration methods" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power over Ethernet" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Preamble time and distance" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0137

Theory session 19

Source text – *Internet Protocols* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Use `Wireshark` "packet-sniffing" software to monitor network traffic on your personal computer, and then identify encapsulation of TCP segments within IP packets, and IP packets within Ethernet frames for some of the captured data.
  → If possible, use a utility such as `netcat` to send a text message from one computer to another, and then use `Wireshark` to intercept and analyze that message!
- Complete "Tracing message routes" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Possible faults in a network" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0138

Theory session 20

Source text – *Internet-based Systems* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Testing sftp access" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Writing a simple HTML file" in the Conceptual Reasoning section of the Questions chapter.
- Complete "HTML color codes" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulty C++ program" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0140

Theory session 21

Source text – *Modbus Networks* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Interpreting a Modbus ASCII message frame" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Modbus ASCII message exchange" in the Quantitative Reasoning section of the Questions chapter.
- Complete "SCADA system fault" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0141

Theory session 22

Source text – *Optical Communication* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Fiber optic data communication
  → Fiber optic cable construction
  → Multi-mode and single-mode optical fibers
  → Fiber optic connectors and routing
  → Fiber optic safety
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Transconductance and transimpedance amplifiers" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power concentration program in Python" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Light direction testing" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0168

Theory session 23

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0285

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Energy efficiency **AC power factor** **Resonance** **Fourier's Theorem** **RMS value**
Filter types and properties **Transformer behavior** **Properties of Wye/Delta networks**
Pulse-width modulation **Heat transfer** **Comparator behavior** **Signal imperfections**
Latch/Flip-flop types and behaviors **Shift register behavior** **Counter behavior**
Programming concepts: *(e.g. data types, math, I/O, conditionals, loops, functions, arrays, pointers)*
Amplifier gain **Transistor biasing** **Decibels** **Current mirror behavior**
Characteristic impedance **Electromagnetic waves** **Modulation**
Maxwell's equations **Antenna behavior** **RF link budgeting**
Positive vs. Negative feedback **Opamp behavior** **Differentiation vs. Integration**
AC motor behavior **Protection zones** **Serial bit encoding** **Channel arbitration**
Serial data frames **Synchronous vs. Asynchronous serial data**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Sketch the signal waveform for an EIA/TIA-232 message representing the ASCII character _____ using ____ data bits, ____ stop bits, and _____ parity at a bit rate of _____ bits per second. You will be allowed to reference an ASCII character table for this problem.

`Grading`

- ◯ [20%] Start, stop, parity, and data bits drawn in the correct chronological order
- ◯ [20%] Correct ASCII code for the requested character
- ◯ [20%] Correct parity bit state
- ◯ [20%] Correct pulse periods for specified bit rate
- ◯ [20%] ASCII code correctly represented as voltage levels

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Use "packet-sniffing" software such as `Wireshark` to intercept a packet containing both TCP and IP data, then comment on their contents.

`Grading`

- ◯ [20%] Correctly identify contents of the message's Ethernet header
- ◯ [20%] Correctly identify contents of the message's IP header
- ◯ [20%] Correctly identify contents of the message's TCP header
- ◯ [20%] Explain how encapsulation is evident within this particular message
- ◯ [20%] Capture some other message that is *not* typical TCP/IP and contrast some of the differences between the TCP/IP message and this new message

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Sketch three different signal waveforms all encoding the same ASCII character (_____ chosen at random by the instructor). One of these waveforms will use NRZ encoding, one Manchester encoding, and the last FSK encoding. Assume a bit rate of _____ bits per second in every case. You will be allowed to reference an ASCII character table for this problem.

`Grading`

- ◯ [20%] Correct pulse periods for specified bit rate
- ◯ [20%] Correct encoding of binary bits as NRZ pulses
- ◯ [20%] Correct encoding of binary bits as Manchester pulses
- ◯ [20%] Correct encoding of binary bits as FSK tones
- ◯ [20%] Describe advantages and/or disadvantages of each encoding scheme

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Reference the datasheet for a Texas Instruments model DAC80501 digital-to-analog converter IC, designed to take in a 16-bit binary word and output an analog voltage proportional to that binary input, and answer the following questions about it while referencing relevant pages of the datasheet.

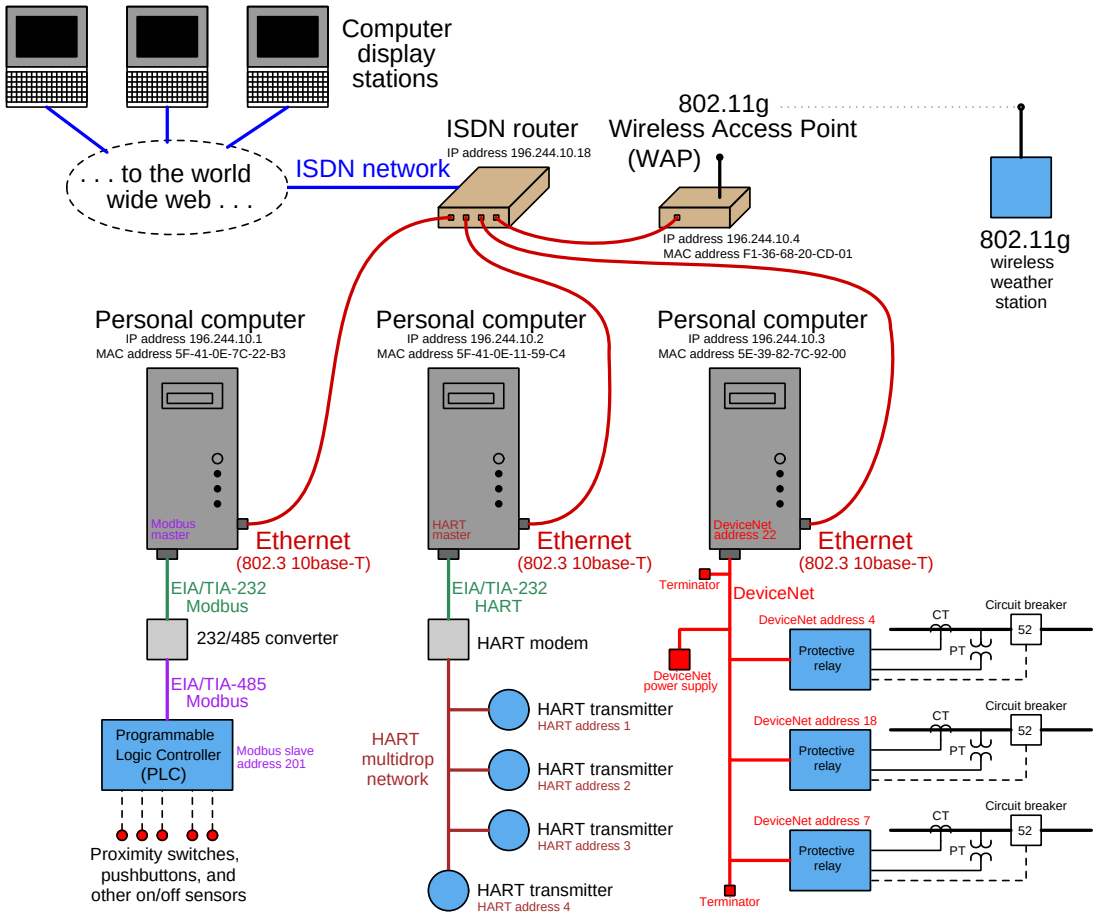
`Grading`

- ◯ [20%] Show how to select either SPI or I2C communication modes for this IC
- ◯ [20%] Identify the maximum serial clock rates for SPI and for I2C modes
- ◯ [20%] Identify some of the setup and hold time specifications for this IC's serial communications, and explain why these specifications are important
- ◯ [20%] Identify where in one of the SPI timing diagrams the data bits are being read by the IC
- ◯ [20%] Identify where in one of the I2C timing diagrams the data bits are being read by the IC

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Something has failed in the SCADA system shown below: employees accessing the computer display stations shown in this diagram can no longer monitor the status of _____ as they could just a day ago.



`Grading`

- ◯ [10%] Identify a fault capable of causing this symptom
- ◯ [10%] Identify another fault capable of causing this symptom
- ◯ [10%] Identify yet another fault capable of causing this symptom
- ◯ [10%] Identify some component failure that could *not* account for this symptom
- ◯ [20%] Describe a set of diagnostic steps useful in determining what has failed and what has not
- ◯ [20%] (for the steps described above being efficient, not using any unnecessary steps)
- ◯ [20%] Explain the purpose of *addressing* as seen for several of the devices in this communications system

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Reference the datasheet for a Texas Instruments model SN75155 line driver and receiver IC to answer the questions below. When presenting your answers, be sure to show where in the datasheet you were able to find the necessary information.

`Grading`

- ◯ [20%] What standard of serial data communication is this device intended to be used for (e.g. Ethernet, Modbus, EIA/TIA-232, EIA/TIA-485, HART, DeviceNet, etc.)?
- ◯ [20%] What voltage levels does its driver section input and output?
- ◯ [20%] What voltage levels does its receiver section input and output?
- ◯ [20%] Driver output state when driver input is floating (based on analysis of the internal schematic diagram)
- ◯ [20%] Correct interpretation of test waveform characteristics: *rise time*, *fall time*, and *propagation times*

Note: full credit given only for answers that are correct <u>and</u> logically supported by trusted principles.

Theory session 24

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Interpret data bits and other data within an RS-232 serial data frame oscillograph.
  EIA/TIA-232 standard, non-return-to-zero (NRZ) encoding, mark and space states, parity bits

- (Question #2) Sketch wire connections to form a serial data network between two or more digital devices.
  EIA/TIA-232 standard, EIA/TIA-485 standard, simplex versus duplex communication, point-to-point versus multipoint networks, termination resistors

- (Question #3) Identify effects of faults in a data network.
  EIA/TIA-232 standard, EIA/TIA-485 standard, simplex versus duplex communication, arbitration protocols, termination resistors

- (Question #4) Determine possible faults in a wireless data network.
  Antenna directionality and polarization, MTU and RTU nodes, arbitration protocols, simplex versus half-duplex communication, RF link budget concepts, Fresnel zones

- (Question #5) Determine possible faults in a wired data network.
  EIA/TIA-232 standard, EIA/TIA-485 standard, Ethernet networks, Ethernet switching, usage of ping utility

- (Question #6 – REVIEW) Calculate and graph voltages, currents, and/or stored energy values over time for a resistor-capacitor circuit.
  Properties of series and parallel networks, behaviors of sources and loads, capacitor behavior, inverse exponential calculations, conservation of energy, Kirchhoff's Voltage Law, capacitor energy calculation, graph sketching

- (Question #7 – REVIEW) Calculate and graph voltages, currents, and/or stored energy values over time for a resistor-inductor circuit.
  Properties of series and parallel networks, behaviors of sources and loads, inductor behavior, inverse exponential calculations, conservation of energy, Kirchhoff's Voltage Law, inductor energy calculation, graph sketching

- (Question #8 – REVIEW) Interpret amplitude values (peak, peak-peak, RMS), period values, phase shifts, and/or frequency values from an oscillograph display.
  Oscilloscope operation, AC measurements, RMS vs peak ratios for sine and square and triangle/ramp waveforms

- (Question #9 – REVIEW) Determine the length of a transmission line given reflectometry data, or vice-versa.
  Velocity factor, speed of light, oscillograph display interpretation, conversions between metric and imperial units of length

file wt_0275

Theory session 25

Source text – *Introduction to RF* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Characteristics of RF
  → Skin effect
  → Balanced versus unbalanced signals
  → RF cabling
  → RF connectors
  → PCB layout for high frequencies
  → Near-field testing
  → RF safety
- Examine and reflect on the Example: near-field probing inside a PC section of the Case Tutorial chapter, and answer the following questions:
  → What useful information may we discern from these near-field probing examples?
  → Why does the H-field probe provide such different results when positioned differently over the PCB?
- Locate the datasheet for the Texas Instruments model TRF37A73 RF amplifier (document SLASE39, dated May 2014) and answer the following questions based on information within the document:
  → Is the RF input to this amplifier balanced or unbalanced?
  → Is the RF output from this amplifier balanced or unbalanced?
  → Why does it matter that both the amplifier's input and output are "matched" to a value of 50 Ohms?
  → Explain the rationale for the PCB layout guidelines specified in this document.
- Locate the datasheet for the Texas Instruments model CC2591 RF front end (document SWRS070B, revised September 2014) and answer the following questions based on information within the document:
  → Is the antenna signal connection to this amplifier balanced or unbalanced?
  → How much receiver gain does this IC provide?
  → How much transmitter output power does this IC provide?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0256

Theory session 26

Source text – *Introduction to Modulation* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Frequency-shifting
- Examine and reflect on the Example: balanced mixer frequencies section of the Case Tutorial chapter, and answer the following questions:
  → Explain how each of the frequencies in the output signal may be calculated from the input frequencies
  → Sketch a frequency-domain plot for any of the given examples
- Complete "Bat sonar detector" in the Conceptual Reasoning section of the Questions chapter.
- Complete "High-side versus low-side injection" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- The "Example: downconverting AM receiver" section of the Case Tutorial chapter shows an AM receiver block-diagram with downconverted frequency values annotated throughout, which may serve to better illustrate how mixers are used to shift RF signal frequencies without losing any essential information modulated on the original signal.

  file wt_0237

Theory session 27

Source text – *Smith Charts* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Phasor diagram review
  → The basic Smith Chart
  → Frequency sweeps
  → Fine-resolution Smith Charts
- Complete "Network frequency-sweep tests" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Plotting component impedances on a Smith Chart" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Frequency-sweep simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Determine which of the calculated results listed in "Practice: complex number calculations" of the Quantitative Reasoning section of the Questions chapter could be most easily plotted on a Smith Chart. *Hint: feel free to alter the "standard" 50 Ohm value of the Smith Chart if this helps with some of the examples!*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0259

Theory session 28

Source text – *Introduction to VNA Basics*, published by Tektronix

EET Reference collection – `EETREF/Tutorials/Tektronix_Intro_to_VNA_Basics.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial in its entirety and answer the following questions:
  - → What differentiates a VNA from test equipment such as a signal generator, an oscilloscope, or a spectrum analyzer?
  - → Identify the components within the "RF Front-End" block diagram (figure 4), and explain how a VNA could be useful in testing each of those components
  - → What are *S-parameters* (also known as *scattering parameters*) in general? Specifically, what do S_{11}, S_{21}, S_{22}, and S_{12} mean?
  - → *Calibration* is an important topic for VNAs, and is something you (the user) must do each and every time before using a VNA to test something. Explain why "user calibration" is necessary and how this differs from "factory calibration".
  - → What do "open", "short", and "load" refer to in the context of user calibration?
  - → What is a *swept frequency* test, and where might we apply such a test?
  - → What is a *swept power* test, and where might we apply such a test?
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Sketch a diagram showing how a VNA could be used to test the performance of a low-pass filter network, and identify the proper S-parameter designation for this type of test.
- Sketch a diagram showing how a VNA could be used to measure the inductance of a custom inductor you wind, and identify the proper S-parameter designation for this type of test.
- Hands-on experimentation with a real VNA (e.g. NanoVNA) during the class session:
  - → User calibration
  - → Resistor, capacitor, inductor testing

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0252

Theory session 29

Source text – *Smith Charts* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Impedance and admittance Smith Charts
  → Series-parallel analysis using Smith Charts
- Examine and reflect on the Example: frequency-sweeps of RLC network impedances section of the Case Tutorial chapter, and answer the following questions:
  → For each of the curves plotted, identify which end of the curve represents the low-frequency end of the sweep test and which end represents the high
  → Explain why, as best you can, each curve has the shape it does based on the topology of its respective network (e.g. series, parallel, series-parallel)
- Complete "Smith Chart test of a dipole antenna" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Frequency-sweep test modifications" in the Quantitative Reasoning section of the Questions chapter.
- Locate the "CC1020 Low-Power RF Transceiver for Narrowband Systems" datasheet (document SWRS046I revised Sep 2018, found in the `Datasheets/RF` directory of your EETREF document collection) and answer the following questions:
  → Identify the range of input impedance vaules for this transceiver's LNA (Low-Noise Amplifier) as shown on a Smith Chart
  → Identify the range of optimum load impedance vaules for this transceiver's PA (Power Amplifier) as shown on a Smith Chart
  → Propose a reasonable explanation for the "loops" seen in some of these Smith Chart frequency sweep tests
  → What type of serial digital protocol does this particular IC employ to interface with other digital devices?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0260

Theory session 30

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Impedance review
  → Natural frequency, reactance, and impedance
  → Complex frequency and impedance
  → *s* variable summary
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "RC network impedances" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to perform calculations for any of the assigned questions or examples found in the Tutorial.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0280

Theory session 31

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Complete "LR network impedances" in the Quantitative Reasoning section of the Questions chapter.
- Complete "RLC network impedances" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Determining s from oscillographs" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to perform calculations for any of the assigned questions.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0289

Theory session 32

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Transfer functions
  → AC network transfer function examples – *just the "Example: LR low-pass filter circuit" and "Example: RC high-pass filter circuit" subsections*
- Complete "Explain this joke" in the Conceptual Reasoning section of the Questions chapter.
- Examine and reflect on the Example: poles and zeroes of a series RC network section of the Case Tutorial chapter, and then try to derive this network's transfer function all on your own.
- Examine and reflect on the Example: poles and zeroes of a series-parallel RC network section of the Case Tutorial chapter, and then try to derive this network's transfer function all on your own.

NOTE: there are many algebraic steps required to write transfer functions, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0281

Theory session 33

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → AC network transfer function examples – *just the "Example: LC tank circuit" and "Example: RLC band-pass filter circuit" subsections*
  → Transfer function summary
- Complete "Pole plots for pendula" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Transfer functions for simple networks" in the Quantitative Reasoning section of the Questions chapter.

NOTE: there are many algebraic steps required to write transfer functions, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0290

Theory session 34

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Use this day to practice analyzing electrical networks and their transfer functions, finishing any unfinished problems from previous theory sessions, working through new Case Tutorial examples, answering any problems from this module that have not been assigned, etc.!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0291

Theory session 35

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0284

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Conservation of Energy **Conservation of Electric Charge** **Definition of Current**
Definition of Voltage **Definition of Resistance** **Behaviors of Sources versus Loads**
Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Energy efficiency **AC power factor** **Resonance** **Fourier's Theorem** **RMS value**
Filter types and properties **Transformer behavior** **Properties of Wye/Delta networks**
Pulse-width modulation **Heat transfer** **Comparator behavior** **Signal imperfections**
Latch/Flip-flop types and behaviors **Shift register behavior** **Counter behavior**
Programming concepts: *(e.g. data types, math, I/O, conditionals, loops, functions, arrays, pointers)*
Amplifier gain **Transistor biasing** **Decibels** **Current mirror behavior**
Characteristic impedance **Electromagnetic waves** **Modulation**
Maxwell's equations **Antenna behavior** **RF link budgeting**
Positive vs. Negative feedback **Opamp behavior** **Differentiation vs. Integration**
AC motor behavior **Protection zones** **Serial bit encoding** **Channel arbitration**
Serial data frames **Synchronous vs. Asynchronous serial data** **Signal mixing**
Skin effect **Near vs. Far EM fields** **Smith charts** **s-domain transfer functions**
Poles vs. Zeroes **Network S-parameters** **Balanced vs. Unbalanced signals**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Sketch two oscillographs illustrating a particular type of signal modulation chosen by the instructor from the list below. The two oscillographs should show (1) an analog example of a modulated signal, and (2) a digital example of a modulated signal.

- Amplitude modulation (AM)
- Frequency modulation (FM)
- Pulse-width modulation (PWM)
- Pulse-density modulation (PDM)

`Grading`

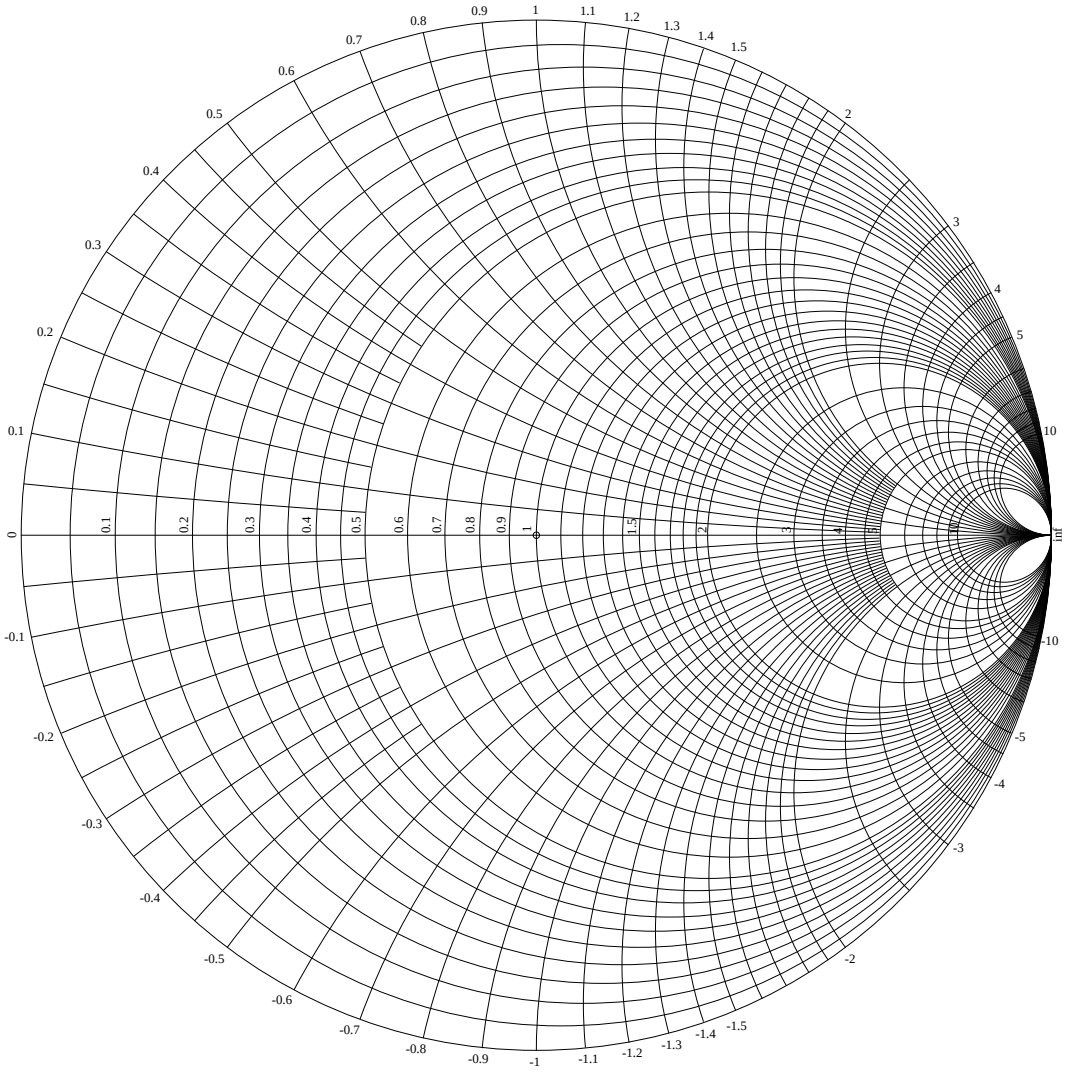
◯ [20%] Correct analog modulated signal
◯ [20%] Correct digital modulated signal
◯ [20%] Describe an analog baseband signal that would only contain odd harmonics
◯ [20%] Describe an analog baseband signal that would contain both odd and even harmonics
◯ [20%] Identify pros and cons of AM versus FM

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Plot the impedance of a custom-made toroidal inductor on a Smith chart, given the following information (chosen at random by the instructor):

- Inductance factor (A_L) for the ferromagnetic toroid
- Number of turns of wire wrapped around (through) the toroid
- Starting frequency of VNA sweep test
- Ending frequency of VNA sweep test
- Normalizing impedance for the Smith chart



`Grading`

◯ [20%] Correct numerical impedance value at starting frequency
◯ [20%] Correct location on Smith chart at starting frequency
◯ [20%] Correct numerical impedance value at ending frequency
◯ [20%] Correct location on Smith chart at ending frequency
◯ [20%] Correct path on Smith chart for the sweep test

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

The following computer program performs a frequency-sweep test on a series RLC network from 1 MHz to 15 MHz. Modify this program to perform a frequency-sweep test on a different network from _____ MHz to _____ MHz in ____ MHz increments. Component values for your program's simulation are shown in the instructor-draw schematic below the sample code listing:

```
#include <stdio.h>
#include <math.h>
#include <complex.h>

int main (void)
{
  float f, f_start = 1e6, f_end = 15e6, L = 47e-6, R = 1.5e3, C = 33e-12;
  float complex s, j = I, Zl, Zc, Zt;

  for (f = f_start ; f <= f_end ; f = f + 1e6)
  {
    s = 0 + (j * 2 * M_PI * f);
    Zl = s * L;
    Zc = 1.0 / (s * C);
    Zt = R + Zl + Zc;

    printf("\%.1f MHz   ", f / 1e6);
    printf("\%.2f + \%.2fj Ohms   ", creal(Zt), cimag(Zt));
    printf("\%.2f Ohms @ \%.2f deg \n", cabs(Zt), carg(Zt) * 180 / M_PI);
  }

  return 0;
}
```

Circuit schematic: *(instructor provides)*

Grading

- ◯ [20%] Demonstrate the edited C code compiles without error
- ◯ [20%] Correct explanation(s) for all code revisions
- ◯ [20%] Identify whether or not a condition of *resonance* is reached in this sweep
- ◯ [10%] Correct simulated Z_{total} at starting frequency verified by manual calculations
- ◯ [10%] Correct simulated Z_{total} at ending frequency verified by manual calculations
- ◯ [20%] Edit and re-run to simulate ____ failing (*open*/*shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

The following computer program performs a frequency-sweep test on a series RLC network from 1 MHz to 15 MHz. Modify this program to perform a frequency-sweep test on a different network from _____ MHz to _____ MHz in ____ MHz increments. Component values for your program's simulation are shown in the instructor-draw schematic below the sample code listing:

```
from math import *
from cmath import *

f_start = 1e6 ; f_end = 15e6 ; L = 47e-6 ; R = 1.5e3 ; C = 33e-12

f = f_start

while (f <= f_end):
   s = complex(0, 2*pi*f)
   Zl = s * L
   Zc = 1 / (s * C)
   Zt = R + Zl + Zc
   print(f/1e6, "MHz", f"{Zt.real:.2f}", "+", f"{Zt.imag:.2f}", "j Ohms", end=" ")
   print(f"{abs(Zt):.2f}", "Ohms @", f"{degrees(phase(Zt)):.2f}", "deg")
   f = f + 1e6
```

Circuit schematic: *(instructor provides)*

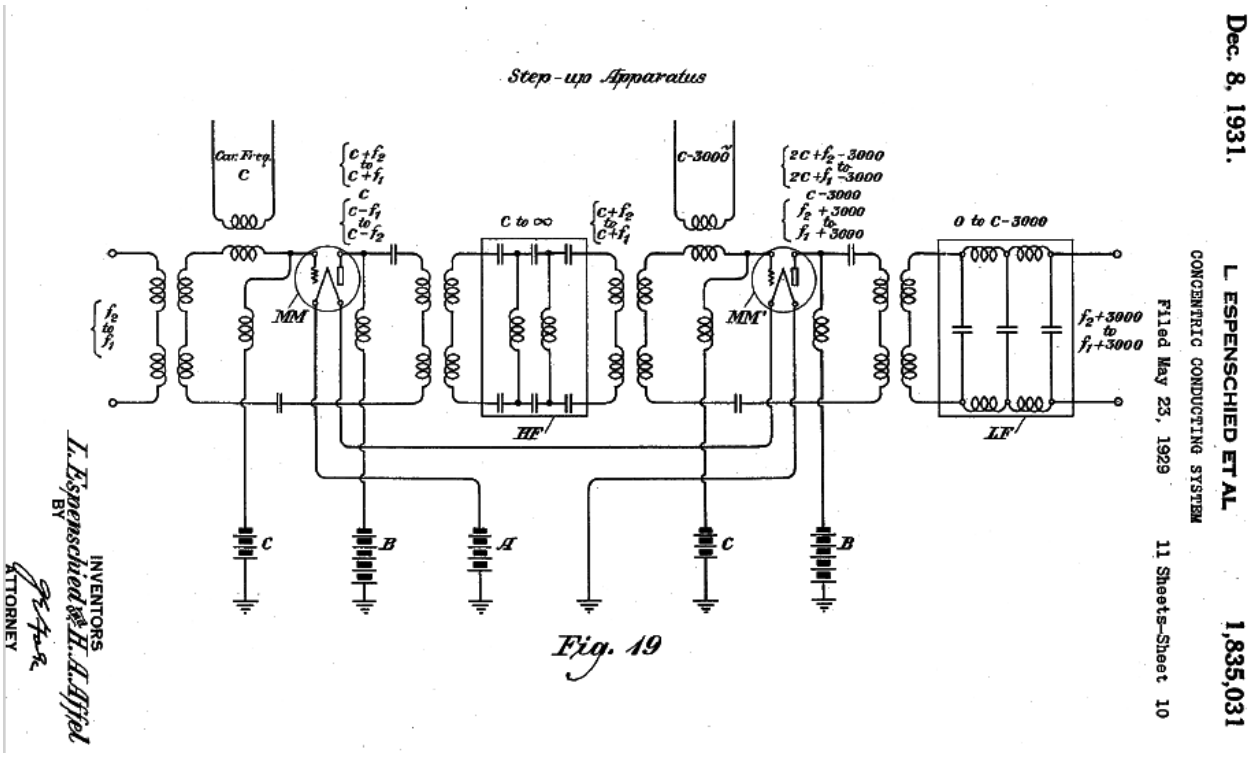
Grading

- ◯ [20%] Demonstrate the edited Python code interprets without error
- ◯ [20%] Correct explanation(s) for all code revisions
- ◯ [20%] Identify whether or not a condition of *resonance* is reached in this sweep
- ◯ [10%] Correct simulated Z_{total} at starting frequency verified by manual calculations
- ◯ [10%] Correct simulated Z_{total} at ending frequency verified by manual calculations
- ◯ [20%] Edit and re-run to simulate ____ failing (*open*/*shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

The following schematic diagram is from a 1931 US patent (Lloyd Espenschied and Herman Affel, US Patent number 1,835,031, "Concentric Conducting System", granted 8 December 1931) showing a two-stage mixer circuit using vacuum tubes rather than transistors. Its purpose was to take a low-frequency audio signal with a frequency range spanning from f_1 to f_2 and shift that band upwards by exactly 3 kHz, as part of a "trunked" telephone system:



The instructor will choose frequency values suitable for analysis of this circuit:

f_1 = Lowest frequency contained in the audio signal band = _____

f_2 = Highest frequency contained in the audio signal band = _____

c = Carrier frequency = _____

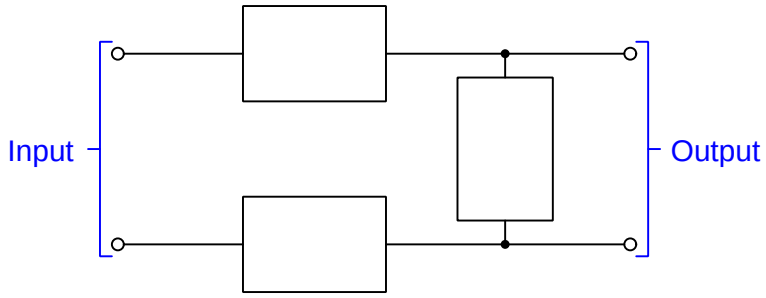
Grading

- ◯ [20%] All frequencies present at the output of the first mixer stage
- ◯ [20%] All frequencies present at the output of the high-pass filter stage
- ◯ [20%] All frequencies present at the output of the second mixer stage
- ◯ [20%] All frequencies present at the output of the low-pass filter stage
- ◯ [20%] Is there any signal *leakage* in either of these mixer stages based on the information given in the schematic?

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Determine the poles and zeroes of the following network, with component types and values chosen randomly by the instructor:



`Grading`

- ◯ [20%] Complex frequency of any pole for this network, if one exists
- ◯ [20%] Complex frequency of any zero for this network, if one exists
- ◯ [20%] Sketch a pole-zero plot showing all poles and zeroes for this network
- ◯ [10%] Explain what it means for a network to have a zero with value of _____
- ◯ [10%] Explain what it means for a network to have a pole with value of _____
- ◯ [20%] What type of *filter* this network represents

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Your instructor will run the `sp` series-parallel resistor simulation program to generate a simulation of a four-resistor series-parallel network powered by either a voltage source or a current source, all resistor values provided by the simulation as well as one resistor's voltage drop, current, or power dissipation. From this you must calculate parameters (mostly voltages and currents) for the source and for all the other resistors.

`Grading`

- ◯ [20%] Voltage and current for the source
- ◯ [20%] Remaining two parameters for the one resistor whose parameter was presented by the simulation
- ◯ [20%] Voltage and current for the next resistor
- ◯ [20%] Voltage and current for the next resistor
- ◯ [20%] Voltage and current for the next resistor

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 36

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Plot the complex-impedance values of a simple RC or RL or LC network at a single frequency on an impedance (Z) Smith Chart.
  Smith Charts, series and parallel AC impedance calculations, complex numbers

- (Question #2) Re-sketch the results of a frequency-sweep test for an RLC network on an impedance (Z) Smith Chart given qualitative changes made to that network, such as a component failing open or shorted, a new component added to it, etc.
  Smith Charts, general effects of opens versus shorts, series and parallel resonance, properties of series versus parallel impedances, properties of series versus parallel inductances, properties of series versus parallel capacitances, complex numbers, VNA operation

- (Question #3) Identify input or output signal frequencies for a two-input mixer circuit given signal waveform descriptions and/or oscillographs.
  Balanced versus unbalanced mixer operation, heterodyning, spectrum analyzer display interpretation, oscillograph interpretation, RF image frequencies, harmonic frequencies for different wave-shapes, waveform period versus frequency

- (Question #4) Determine zeroes and poles for a simple (two or three component) RC or LR network with specified component values.
  Complex frequency, transfer functions, decay rate, natural frequency, pole-zero plots, s-based impedance calculations, voltage divider formula, eliminating compound fractions in algebraic expressions

- (Question #5 – REVIEW) Sketch phasor diagrams of AC quantities in simple circuits.
  Ohm's Law, properties of series networks, properties of parallel networks, Kirchhoff's Laws, complex-number arithmetic, AC phasors, phasor diagrams, power factor

- (Question #6 – REVIEW) Identify RF signal modulation based on oscillograph or spectrum displays.
  Modulation schemes, AC quantities, oscilloscope display interpretation, spectrum analyzer display interpretation, sinusoidal decomposition (Fourier analysis), sidebands

- (Question #7 – REVIEW) Compute power gains/losses in radio communication systems using decibels.
  Decibels, power dissipation in RF cables, antenna gain, RF link budgets

- (Question #8 – REVIEW) Design and sketch an operational amplifier circuit with a specified voltage gain.
  Ohm's Law, general amplifier behavior, voltage gain, negative feedback, opamp behavior, inverting versus non-inverting opamp circuits

- (Question #9 – REVIEW) Calculate voltage and current values within an arbitrary operational amplifier circuit given component values and some given voltage and/or current values.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, BJT amplifier behavior, negative feedback, opamp behavior, comparator behavior

file wt_0273

Theory session 37

Source text – *Sensors Overview* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter. Feel free to *skip* all subsections dealing with chemical sensors:
  → Signals, sensors, and switches
  → Potentiometric sensors
  → Amperometric sensors
  → Resistive sensors
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Thermistor bridge circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Balancing a resistive bridge" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Discharging capacitor simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0146

Theory session 38

Source text – *Operational Amplifiers* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read the Tutorial chapter as necessary to refresh your memory on this subject.
- Examine and reflect on the Example: opamp networks responding to various inputs section of the Case Tutorial chapter, and answer the following questions:
  → What does it mean that all of these circuits are powered by a "split" DC supply?
  → Identify in which of these examples the feedback loop is broken (i.e. where the opamp operates in "open-loop" mode)?
- Complete "Multi-stage amplifier gains" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Adding diodes to an inverting amplifier" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Internal faults in a model 324" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Testing common-mode rejection" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0283

Theory session 39

Source text – *Op Amps For Everyone*, written by Ron Mancini

EET Reference collection – `EETREF/Tutorials/TI_op_amps_for_everyone.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Locate the *Op Amps For Everyone* tutorial (document SLOD006B revised August 2002, found in the `Tutorials/` directory of your EETREF document collection) and read Chapter 3 ("Development of the Ideal Op Amp Equations") to answer the following questions:
  - → Explain in your own words the five assumptions made by the author regarding ideal opamp behavior
  - → What does it mean to say that "the frequency response of the ideal op amp is flat"?
  - → Which law of Kirchhoff's is used in the development of equation 3-4?
  - → What is "common-mode" voltage, and how does this concept apply to any of the opamp circuits shown in this chapter?
  - → What special considerations must be given to video signal applications?
  - → How may capacitors be applied to opamps to form filter networks?
- Read Chapter 6 ("Development of the Non Ideal Op Amp Equations") to answer the following questions:
  - → What is loop gain in a feedback circuit and what defines its value?
  - → Why is there "always a tradeoff between error and stability"?
  - → Explain the problem-solving technique of using a "dummy variable" shown in section 6.3
  - → This document makes frequent use of the term "transfer function" when describing opamp circuits; based on the author's usage of this term, what do you think would be a good general definition for a transfer function?
- **Coding challenge** – write a simple computer program in a text-based language simulating any of the opamp example circuits shown in chapter 3 of the tutorial, your program only making use of foundational circuit concepts such as Ohm's Law, Kirchhoff's Law, cardinal rule of negative feedback, etc.

Discuss as a group your learning experience studying operational amplifiers again after having studied it some time in the past. Which concepts were clearer this time than during the first time you encountered this topic? Were there any concepts that made *less* sense to you this time around? Are there questions you have now that you didn't think of asking last time?

After you graduate from this program, you will enter a career where the need for continual learning never ceases. Much of your learning after graduation will be informal, driven by your own curiosity and needs. What lessons can you take from your experience today (i.e. reviewing a previously-learned concept) that might be beneficial to your self-directed learning in the future? What does today's experience tell you about how your mind embraces complex topics? What does today's experience tell you about resources available for your own self-directed education?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0272

Theory session 40

Source text – *Analog-Digital Conversion* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → ADCs and DACs
  → Resolution
  → ADC sampling and aliasing
  → DAC circuitry: binary-weighted
  → DAC circuitry: R-2R
  → ADC circuitry: flash conversion
  → ADC circuitry: tracking conversion
  → ADC circuitry: successive approximation conversion
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Scaling and overvoltage protection for ADC" in the Conceptual Reasoning section of the Questions chapter.
- Complete "ADC0804 signal values" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Over/under-flowing ADC" in the Diagnostic Reasoning section of the Questions chapter.
- If time permits, compile the C code shown in the Example: aliasing a 10 kHz sine wave section of the Case Tutorial chapter and experiment with the effects of sampling a sine wave signal at different rates.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.

  file wt_0059

Theory session 41

Source text – *Signal Referencing and Scaling* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "ADC measurements in a voltage divider" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Resistor sizing" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Temperature measurement simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Damaged data acquisition system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0152

Theory session 42

Source text – *Operational Amplifiers* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Amplification with offset
- Complete "Opamp signal scaling circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Constant-current electronic load circuit" in the Quantitative Reasoning section of the Questions chapter.
- Sketch a design for an electronic load circuit capable of performing more than one function (e.g. one mode for constant-current, another for constant-voltage). Make this design as complete as you can, with component part numbers, necessary heat-sinking, etc.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0276

Theory session 43

Source text – *Data Acquisition Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Examine and reflect on the Example: using Python to control a LabJack model U3 DAQ section of the Case Tutorial chapter, and answer the following questions:
  - → How are instructions repeatedly executed within a Python program?
  - → What types of signals can the `FIO` channels on this particular DAQ handle?
  - → How exactly are `FIO` channels configured as either inputs or outputs?
  - → What practical applications might benefit from the use of *hardware counters* built into a DAQ?
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Connecting strain gauges to a DAQ" in the Conceptual Reasoning section of the Questions chapter.
- Complete "DC circuit monitor" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Measuring speed with a DAQ" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0153

Theory session 44

Source text – *Advanced Filter Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Basic filter networks
  → Output-limited filter networks
  → Balanced versus unbalanced filter networks
  → Filter network topology
  → Improving roll-off
  → Passive filter design
  → If time permits, also read Filter poles and zeroes (this explains those weird-looking Bode plots)
- Complete "Filter component value scaling" in the Conceptual Reasoning section of the Questions chapter.
- Read the Butterworth passive filter designer using C++ section of the Programming References chapter and answer the following questions:
  → What is the purpose of the data stored in this program's array?
  → Identify where in this program impedance scaling is performed
  → Identify where in this program frequency scaling is performed
  → Explain how the program determines whether the component value being scaled is a capacitance or an inductance
- Complete "RC filter component selection program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- Sections of the Case Tutorial chapter contains circuit examples which may serve as practice problems.
- Butterworth and Chebyshev component values sections of the Derivations and Technical References chapter.

  file wt_0271

Theory session 45

Source text – *Application Note 779 – A Basic Introduction to Filters*, written by Kerry Lacanette

EET Reference collection – `EETREF/Application_Notes/TI_a_basic_introduction_*.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- In this Application Note, the author presents a number of different passive filter networks containing components whose values are all one (e.g. 1 Ohm, 1 Farad, 1 Henry), and as a result of this simplification the corresponding transfer functions contain no R, C, or L variables. Show how each of the following transfer functions may be derived using the simple component values shown.
  - → Figure 2 – band-pass filter network
  - → Figure 6 – band-stop filter network
  - → Figure 9 – low-pass filter network
  - → Figure 12 – high-pass filter network
- What is gained by simplifying all component values to be one (1)? Also, what is lost?
- In this Application Note the author states "*The transfer function defines the filter's response to any arbitrary input signal, but we are most often concerned with its effect on continuous sine waves.*" How would transfer functions still be useful to us if we knew for a fact that the applied signal to a network was non-sinusoidal?
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading.

Source text – *The S variable* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Examine the pole-zero plotter program written in C++ shown in the Programming References chapter.
  - → Explain how this program functions
  - → If time permits, run this program on your own and use its text-based output to create a three-dimensional pole-zero plot in a program such as Microsoft Excel using a "surface" chart type.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0282

Theory session 46

Source text – *Advanced Filter Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Active filters
  → Active filter design
  → Active filter transfer functions
- Complete "Limiting-case analysis of Sallen-Key filter networks" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sallen-Key active low-pass filter design" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Sallen-Key active high-pass filter design" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0328

Theory session 47

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

One of the most important skills for success in these assessments is knowing how to check your work as you progress through each problem! Applying mental math and estimations along the way for each calculated result is vital for avoiding the pitfall of a wrong result compromising future answers.

file wt_0119

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Energy efficiency **AC power factor** **Resonance** **Fourier's Theorem** **RMS value**
Filter types and properties **Transformer behavior** **Properties of Wye/Delta networks**
Pulse-width modulation **Heat transfer** **Comparator behavior** **Signal imperfections**
Latch/Flip-flop types and behaviors **Shift register behavior** **Counter behavior**
Programming concepts: *(e.g. data types, math, I/O, conditionals, loops, functions, arrays, pointers)*
Amplifier gain **Transistor biasing** **Decibels** **Current mirror behavior**
Characteristic impedance **Electromagnetic waves** **Modulation**
Maxwell's equations **Antenna behavior** **RF link budgeting**
Positive vs. Negative feedback **Opamp behavior** **Differentiation vs. Integration**
AC motor behavior **Protection zones** **Serial bit encoding** **Channel arbitration**
Serial data frames **Synchronous vs. Asynchronous serial data** **Signal mixing**
Skin effect **Near vs. Far EM fields** **Smith charts** **s-domain transfer functions**
Poles vs. Zeroes **Network S-parameters** **Balanced vs. Unbalanced signals**
System stability **Aliasing** **Linear equations** *(e.g. $y = mx + b$)* **Digital resolution**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations** *Strategy:* **Dimensional analysis**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

`Grading`

- ◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Determine the listed parameters for a ____ bit analog-to-digital converter (ADC) circuit with an input range voltage range of _____ to _____ and a sampling rate of _____ samples per second.

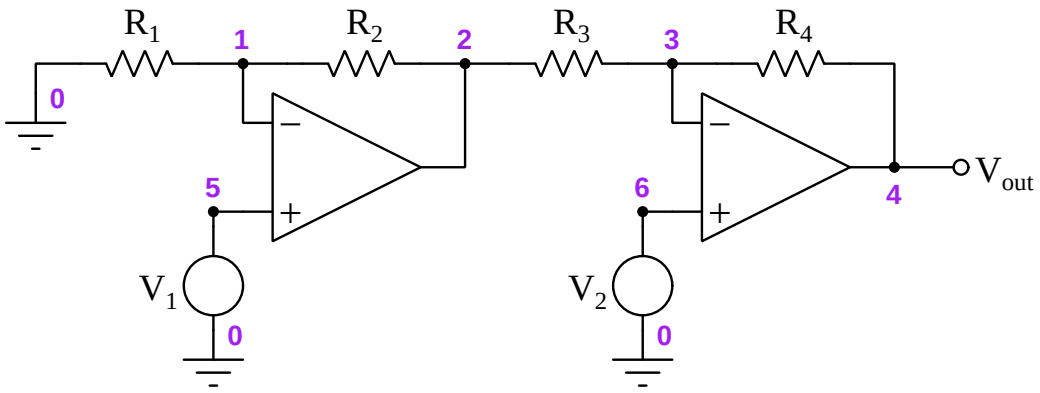
`Grading`

- ◯ [20%] Digital output in binary for an input voltage of _____ Volts
- ◯ [20%] Digital output in decimal for an input voltage of _____ Volts
- ◯ [20%] Digital output in hexadecimal for an input voltage of _____ Volts
- ◯ [20%] Practical bandwidth (frequency range) of voltage measurement for AC signals
- ◯ [20%] Resolution of this ADC in milliVolts

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

(Component values randomly chosen by instructor):



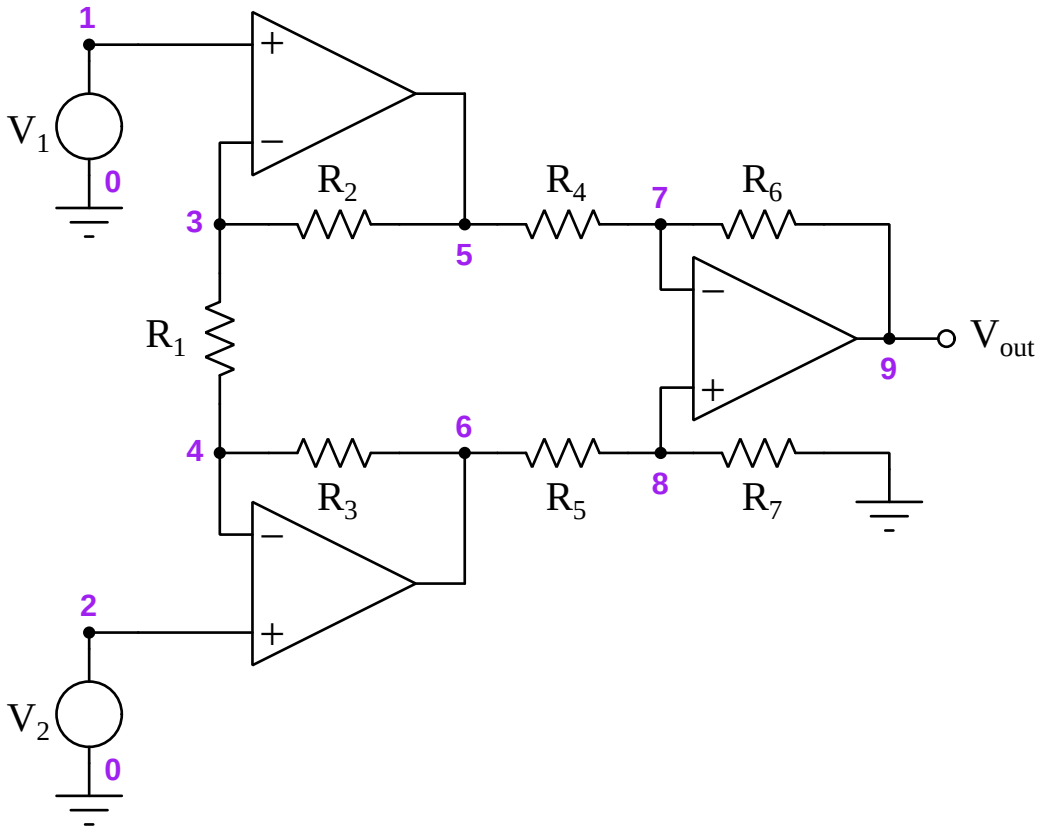
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 5 (I_5)
- ◯ [20%] All current magnitudes and directions entering and exiting node 2
- ◯ [20%] Voltage magnitude and polarity between nodes 3 and 1 (V_{3-1})
- ◯ [20%] Voltage magnitude and polarity of V_{out}

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

(Component values randomly chosen by instructor):



`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] All current magnitudes and directions entering and exiting node 6
- ◯ [20%] Voltage magnitude and polarity between nodes 5 and 8 (V_{5-8})
- ◯ [20%] Voltage magnitude and polarity of V_{out}

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Write a transfer function, and determine poles and zeroes, for the following filter network (sketched by the instructor):

Grading

- ◯ [20%] Identify the type of filter (*low-pass*, *high-pass*, *band-pass*, or *band-stop*)
- ◯ [20%] Correct (unsimplified) transfer function
- ◯ [20%] Correct (simplified to have no compound fractions) transfer function
- ◯ [20%] Correct identification of zero(es)
- ◯ [20%] Correct identification of pole(s)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Sketch a sensor network capable of sensing (*temperature/strain/light/speed*) that will output an (*increasing/decreasing*) voltage signal as the sensed variable increases. Include an operational amplifier in your circuit to provide a specified voltage gain of _____.

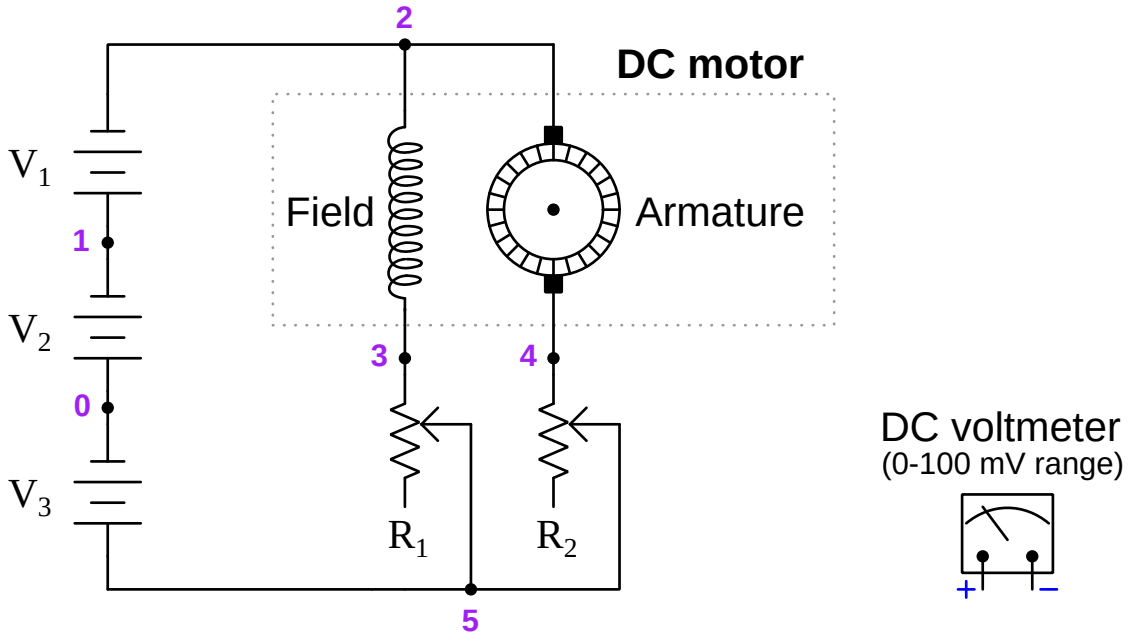
`Grading`

- ◯ [20%] Explain the operating principle of the sensor chosen for your circuit
- ◯ [20%] Identify the effects of the sensor failing (*open/shorted*)
- ◯ [20%] Identify how to (*increase/decrease*) voltage gain in the circuit
- ◯ [20%] Re-design the circuit to have the opposite direction of response as originally specified
- ◯ [20%] Explain whether your circuit will be able to function using a "single" DC power supply, or if a "split" DC power supply will be required

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #7

Determine how to interface a voltmeter (with a 0 to 100 milliVolt range) to serve as an analog indicator for (*field current/armature current/total current/total voltage/armature voltage/field voltage*) in this DC motor circuit. Component values will be randomly chosen by instructor (including field and armature winding resistance values), as well as maximum field and armature current values. Feel free to add components as necessary into the circuit:



Grading

- ◯ [20%] Voltmeter polarity is proper for the application
- ◯ [20%] Voltmeter will not be over-ranged for maximum expected measurement value
- ◯ [20%] Voltmeter will indicate at least 50% of full-scale for maximum expected measurement value
- ◯ [20%] Any additions/edits to the circuit will not compromise its ability to achieve full-voltage or full-current operation
- ◯ [20%] Voltage magnitude and polarity between nodes 0 and 2 (V_{0-2})

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Modify this C-language computer program to simulate the behavior of the operational amplifier circuit sketched by the instructor (below the code listing). Component and DC source values will be randomly assigned by the instructor, as will the topology of the circuit:

```
#include <stdio.h>
#include <math.h>
int main (void) {
  float R[5]; // Array of resistor values
  float Vsig, Vout, Vplus = 15.0, Vminus = -15.0;
  while(1) {
    printf("Enter signal voltage:  ");
    scanf("%f", &Vsig);
    // Circuit simulation code goes here, inside of loop .  .  .
    // Output voltage limiting code goes here, inside of loop .  .  .
    printf("Output voltage = %f Volts\n", Vout);
  }
  return 0; }
```

Grading

- ◯ [20%] Demonstrate the edited C code compiles without error
- ◯ [20%] Correct output voltage at input of _____ Volts
- ◯ [20%] Correct output voltage at input of _____ Volts
- ◯ [20%] Demonstrate output signal limited so as never to exceed rail voltages
- ◯ [20%] Edit and re-run simulation assuming ____ fails (*open*/*shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 48

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Calculate voltage, current, and/or resistance within an analog sensor circuit.
  Ohm's Law, Kirchhoff's Laws, ideal versus real sources, properties of series and parallel networks, bridge networks, interpreting sensor response graphs

- (Question #2) Design and sketch a signal-conditioning circuit for an analog-digital converter (ADC).
  Opamp amplifier circuits, differential amplifier circuits, common-mode voltage, anti-aliasing filters, ADC range and resolution, voltage dividers

- (Question #3) Determine ADC sampling rates, sampling rate requirements, or resolution from oscillographs of real signals.
  Aliasing, the Nyquist Sampling Theorem, waveform period and frequency measurements, anti-aliasing filters, ADC range and resolution

- (Question #4) Sketch wire connections to interface a data acquisition unit (DAQ) to one or more analog sensors.
  Single-ended versus differential voltage measurements, common-mode voltage, bridge networks, shunt resistors

- (Question #5) Determine possible faults in an analog sensing circuit.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, opamp behavior, effects of opens vs. shorts

- (Question #6 – REVIEW) Design and sketch a circuit exhibiting a specified inverse-exponential rise or decay for either voltage or current.
  Properties of series and parallel networks, capacitor behavior, inductor behavior, inverse exponential calculations, qualitative determination of voltages and currents over time for RC and LR networks

- (Question #7 – REVIEW) Calculate voltage and current values within an arbitrary operational amplifier circuit given component values and some given voltage and/or current values.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, BJT amplifier behavior, negative feedback, opamp behavior, comparator behavior

- (Question #8 – REVIEW) Sketch a Thévenin equivalent network for a series-parallel DC resistor circuit.
  Ohm's Law, Kirchhoff's Laws, ideal versus real sources, properties of series and parallel networks, Thévenin's Theorem, Norton's Theorem

- (Question #9 – REVIEW) Design and sketch a passive filter circuit with a specified cutoff frequency and characteristic.
  Filter circuit behavior, capacitive reactance, inductive reactance, resonance

file wt_0274

Theory session 49

Source text – *Electrical Metrology* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → What is metrology?
  → Metrological standards
  → Measurement terminology
  → Measurement uncertainty
  → Proportionate expressions
  → Typical instrument errors
  → Drift and instability
  → Intrinsic noise
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Clock accuracy" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Thermometer calibration results" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Voltmeter calibration results" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Ammeter calibration results" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0268

Theory session 50

Source text – *Electrical Metrology* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following subsections of the Tutorial chapter:
  → Electrical metrology standards – DC voltage standards
  → Electrical metrology standards – Resistance standards
  → Electrical metrology standards – DC current standards
- Locate technical literature for a *Fluke model 5730A multifunction calibrator* and identify the following information within the document(s):
  → How much warm-up time is required when turning it on for the first time in a long while? Why do you think this time is necessary?
  → What are some of the *auxiliary amplifier* options for this unit, and what do they do?
  → Uncertainty specifications for this instrument's output functions – how unstable and/or uncertain are some of the specifications?
- Locate datasheet(s) for precision voltage reference ICs and compare in terms of cost, supply voltage, stability, and absolute accuracy.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0269

Theory session 51

Source text – *Electrical Metrology* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Precision voltage measurement techniques
  → Precision resistance measurement techniques
  → Electrical metrology tools
- Complete "EKG monitor" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Kelvin-Varley voltage divider" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Testing a 250 V meter with a 10 V standard" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, complete "Hamon voltage divider simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0270

Theory session 52

Source text – *Electrical Metrology* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following subsection of the Tutorial chapter:
  → Electrical metrology standards – Frequency and time standards
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Examine and reflect on the Example: GPS receiver data stream section of the Case Tutorial chapter, and answer the following questions:
  → What are some of the data available from an NMEA-0183 formatted message output by a GPS radio receiver?
  → Are there any data fields redundant to each other in the example data capture shown?
- Complete "Measuring time in Python" in the Quantitative Reasoning section of the Questions chapter.
- Download the datasheet for a precision oscillator module and identify the following information within the document:
  → Type of output signal waveform
  → Nominal frequency of the output signal
  → Stability of the output frequency
  → Startup time
  → *Any special features?*

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0287

Theory session 53

Source text – *Phase-Locked Loops* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "CD4046B phase-locked loop applications" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Tone-controlled switching system" in the Conceptual Reasoning section of the Questions chapter.

Note: the Texas Instruments CD4046 application note may be found in your EETREF collection!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0261

Theory session 54

Source text – *Electrical Metrology* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Automated electrical testing
- Examine and reflect on the Example: SCPI control of digital power supply and multimeter section of the Case Tutorial chapter, and answer the following questions:
  → What purpose does the `list_resources` Python instruction fulfill?
  → Identify some of the idiosyncratic parameter settings necessary to make the computer successfully communicate with these two instruments, and where in the Python instructions these particular parameters were set
  → Describe one of the documentation errors that caused problems getting the SCPI commands to work properly
- Locate an online video showing a *flying probe tester* at work and be prepared to share this with your classmates.

Source text – *SCPI Volume 1: syntax and style*

EET Reference collection – `EETREF/Regulatory_Government/SCPI_syntax*.pdf`

- Read the "Foreward" section of Volume 1 (Syntax and Style) within this document, and comment on the history of SCPI
- Reference Volume 4 (Instrument Classes) within this document to answer the following questions:
  → List some of the test instrument types represented by the Chapters of this volume
  → Identify some of the simpler Programming Examples shown in this volume, showing a sequence of SCPI commands intended to control a particular instrument
  → Note how these programming examples only list the SCPI commands themselves, and not the particular programming-language (e.g. C, Python, etc.) instructions necessary to *issue* those SCPI instructions over the network and to the instrument – what would one of the programming examples in this document actually look like if written in Python?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0288

Theory session 55

Source text – *Introduction to Process Control* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → What is Instrumentation?
  → Terms and definitions
  → Control system examples
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Choosing proper controller action" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Negative-feedback PLC control" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Diesel engine speed monitor" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0292

Theory session 56

Source text – *Analog Instrumentation Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → 4 to 20 mA analog current signals
  → Relating 4 to 20 mA signals to instrument variables
- Complete "Instrument range tables" in the Quantitative Reasoning section of the Questions chapter.
- Complete "3-wire RTD temperature transmitter circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in a pressure control system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Failed maple syrup process" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0294

Theory session 57

Source text – *Analog Instrumentation Circuits* learning module

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

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Controller output current loops
  → 4-wire ("self-powered") transmitter current loops
  → 2-wire ("loop-powered") transmitter current loops
  → Instrument loop diagrams
- Complete "Failed flow control system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Faults in an air regulating system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Failed reactor temperature control system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Faulty pH measurement system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0295

Theory session 58

Source text – *Fourth semester practice Comprehensive exam*

URL – `https://ibiblio.org/kuphaldt/socratic/model/ietti236_x1_practice_version.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Browse the contents of this Comprehensive exam and choose at least *five* different questions from within it that you would like to practice together as a group:
  → Question: _____
  → Question: _____
  → Question: _____
  → Question: _____
  → Question: _____

  The entirety of today's theory session will be spent reviewing concepts of your own choosing!

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0293

Theory session 59

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0296

Problem #1

By this point in time, the "Conceptual Toolbox" section of your Theory Journal should contain (at minimum) entries for the following electrical concepts and problem-solving strategies:

Ohm's Law (with all equation forms shown) **Joule's Law** (with all equation forms shown)
Effects of Opens versus Shorts **Resistor Color Codes** **Metric prefixes**
Definition and properties of Series networks **Definition and properties of Parallel networks**
Kirchhoff's Voltage Law **Kirchhoff's Current Law** **Definitions of Ground**
Definition and properties of Bridge networks **Potentiometer behavior**
Max. Power Theorem **Superposition Theorem** **Thévenin's/Norton's Theorems**
Electric versus Magnetic fields **Capacitive energy storage** **Inductive energy storage**
Right-hand Rule(s) of electromagnetism **Faraday's Law of induction** **Lenz's Law**
Electromagnetic relay behavior **NO/NC switch behavior** **Rates of change** ($\frac{dV}{dt}$, $\frac{dI}{dt}$)
"Ohm's Law" for capacitance **"Ohm's Law" for inductance** **Exponential growth/decay**
PN junction diode behavior **BJT types and behavior** **MOSFET types and behavior**
Thyristor types and behavior **Sourcing versus Sinking current** **Transistor saturation**
Logic function truth tables *(e.g. AND, OR, NOT, etc.)* **Logic state voltages**
Boolean SOP/NSOP expressions **ASCII encoding** **Decimal/Binary/Hex numeration**
Energy efficiency **AC power factor** **Resonance** **Fourier's Theorem** **RMS value**
Filter types and properties **Transformer behavior** **Properties of Wye/Delta networks**
Pulse-width modulation **Heat transfer** **Comparator behavior** **Signal imperfections**
Latch/Flip-flop types and behaviors **Shift register behavior** **Counter behavior**
Programming concepts: *(e.g. data types, math, I/O, conditionals, loops, functions, arrays, pointers)*
Amplifier gain **Transistor biasing** **Decibels** **Current mirror behavior**
Characteristic impedance **Electromagnetic waves** **Modulation**
Maxwell's equations **Antenna behavior** **RF link budgeting**
Positive vs. Negative feedback **Opamp behavior** **Differentiation vs. Integration**
AC motor behavior **Protection zones** **Serial bit encoding** **Channel arbitration**
Serial data frames **Synchronous vs. Asynchronous serial data** **Signal mixing**
Skin effect **Near vs. Far EM fields** **Smith charts** **s-domain transfer functions**
Poles vs. Zeroes **Network S-parameters** **Balanced vs. Unbalanced signals**
System stability **Aliasing** **Linear equations** *(e.g. $y = mx + b$)* **Digital resolution**
Measurement uncertainty **Traceability** **Calibration errors** **Control system behavior**
Strategy: **Limiting Cases** *Strategy:* **Thought Experiments** *Strategy:* **Annotating schematics**
Strategy: **Cut-and-Try calculations** *Strategy:* **Dimensional analysis**

Your instructor will randomly select five (5) of these concepts/strategies for you to accurately define and apply to circuit scenario(s) of your choice.

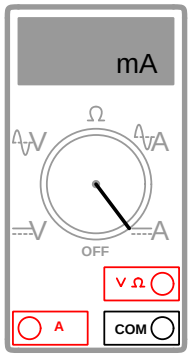
`Grading`

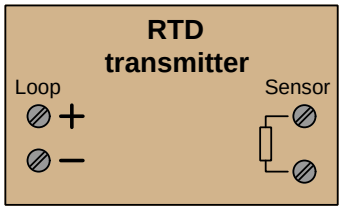
- ◯ [20%] Correct definition and appropriate circuit example for first concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for second concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for third concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fourth concept/strategy
- ◯ [20%] Correct definition and appropriate circuit example for fifth concept/strategy

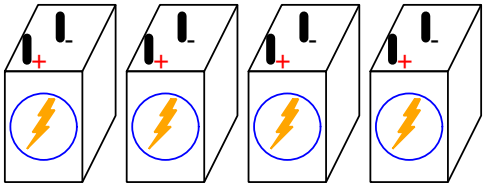
Note: full credit given only for answers that are correct and logically supported by trusted principles.

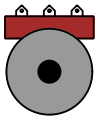
Problem #2

Suppose you needed to simulate an RTD to the input of a temperature transmitter, using a $\frac{3}{4}$-turn potentiometer as a substitute for a 2-wire RTD. Note the labels drawn on the face of the transmitter indicating loop power connections and 2-wire RTD connections:









Sketch the necessary connecting wires so that the simulated RTD signal to the transmitter increases as the potentiometer's shaft is rotated (*clockwise / counter-clockwise*), and so that the multimeter registers the transmitter's 4-20 mA signal (using the batteries as a 24 VDC loop power supply) as a positive numerical value.

`Grading`

- ◯ [20%] Transmitter registers higher temperature as potentiometer is turned the specified direction
- ◯ [20%] Assuming a calibrated range of ____ deg F to ____ deg F, calculate loop current at a simulated temperature of ____ deg F
- ◯ [20%] Predict effect on mA signal as the battery voltage slightly (*increases / decreases*)
- ◯ [20%] Predict effect on mA signal if the potentiometer were to fail (*open / shorted*)
- ◯ [20%] Show where a diode could be inserted into the loop for easy current measurement

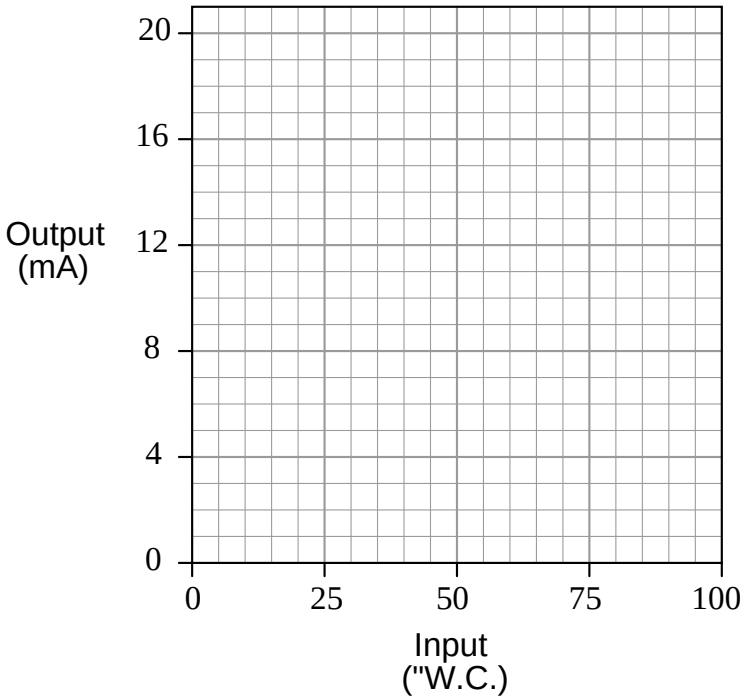
Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

An electronic pressure transmitter has an input range of 0 to 100 inches water column and an output range of 4 to 20 mA. When subjected to a series of known pressures (5-point up/down test), it responds as such:

Applied pressure (" WC)	Output signal (mA)
0	
25	
50	
75	
100	
75	
50	
25	
0	

Graph this instrument's ideal output/input function on the graph below, along with its *actual* function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *linearity*, and/or *hysteresis*).



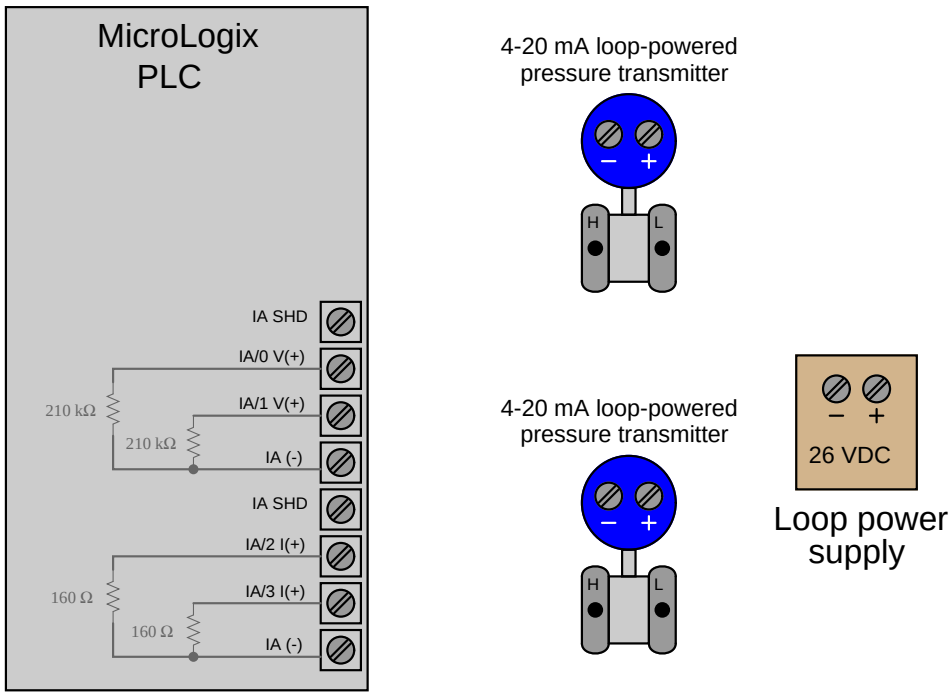
Grading

- ◯ [20%] Proper identification of calibration error type (zero, span, etc.)
- ◯ [20%] Proper sketch of graph according to tabulated values
- ◯ [20%] Calculate output current value at ____ inches of WC applied pressure
- ◯ [20%] Calculate input pressure value at ____ milliAmperes output current
- ◯ [20%] Calculate greatest error (in percent of span) evident in the tabulated values

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

The Rockwell/Allen-Bradley MicroLogix 1000 programmable logic controller (PLC) can handle up to four analog input signals: two with a 0-10 V maximum range and two with a 0-20 mA maximum signal range. This PLC's analog input terminal block looks like this (the internal resistors are shown inside the PLC box):



Sketch the appropriate wiring to connect one of the 4-20 mA loop-powered transmitters to current input IA/2 on the PLC, and the other transmitter to voltage input IA/0 on the PLC, using the one 26 VDC power supply to energize both.

Note: the two "IA SHD" terminals are provided for cable shield conductor attachment. You may ignore cable shield wires and these terminals for simplicity's sake.

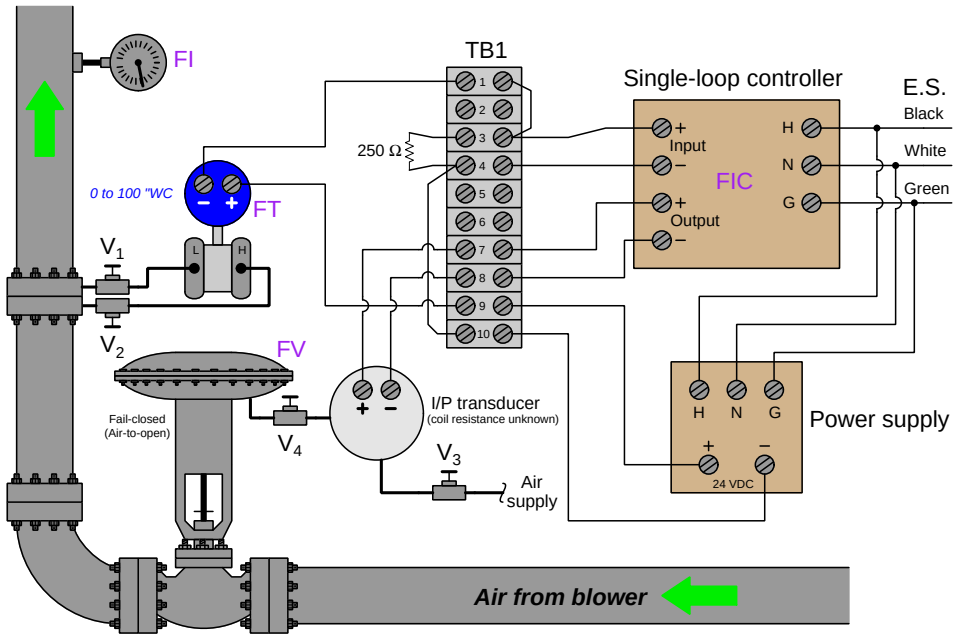
`Grading`

- ◯ [20%] Proper wiring for IA/2 transmitter
- ◯ [20%] Proper wiring for IA/0 transmitter
- ◯ [20%] Annotate all currents in both circuits
- ◯ [20%] Annotate all component voltage drops in both circuits
- ◯ [20%] Calculate analog-to-digital count value for IA/2 assuming a unipolar 12-bit converter operating on a 0-22 mA input range, given an input current signal of ____ mA

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

This single-loop flow control system has a problem – (*instructor describes here*):



Determine the diagnostic value of each of the following tests. Assume only one fault in the system, including any single component or any single wire/cable/tube connecting components together. If a proposed test could provide new information to help you identify the location and/or nature of the one fault, mark "yes." Otherwise, if a proposed test would not reveal anything relevant to identifying the fault (already discernible from the measurements and symptoms given so far), mark "no."

Diagnostic test	Yes	No
Measure AC line voltage		
Measure DC power supply output voltage		
Check pressure transmitter calibration		
Measure transmitter current signal		
Measure resistor voltage drop		
Check flow indicator (FI) reading		
Put controller into manual mode and try to move the valve stem position		
Test air supply for adequate compressed air pressure		
Measure DC voltage between TB1-3 and TB1-4		
Measure DC voltage between TB1-7 and TB1-8		

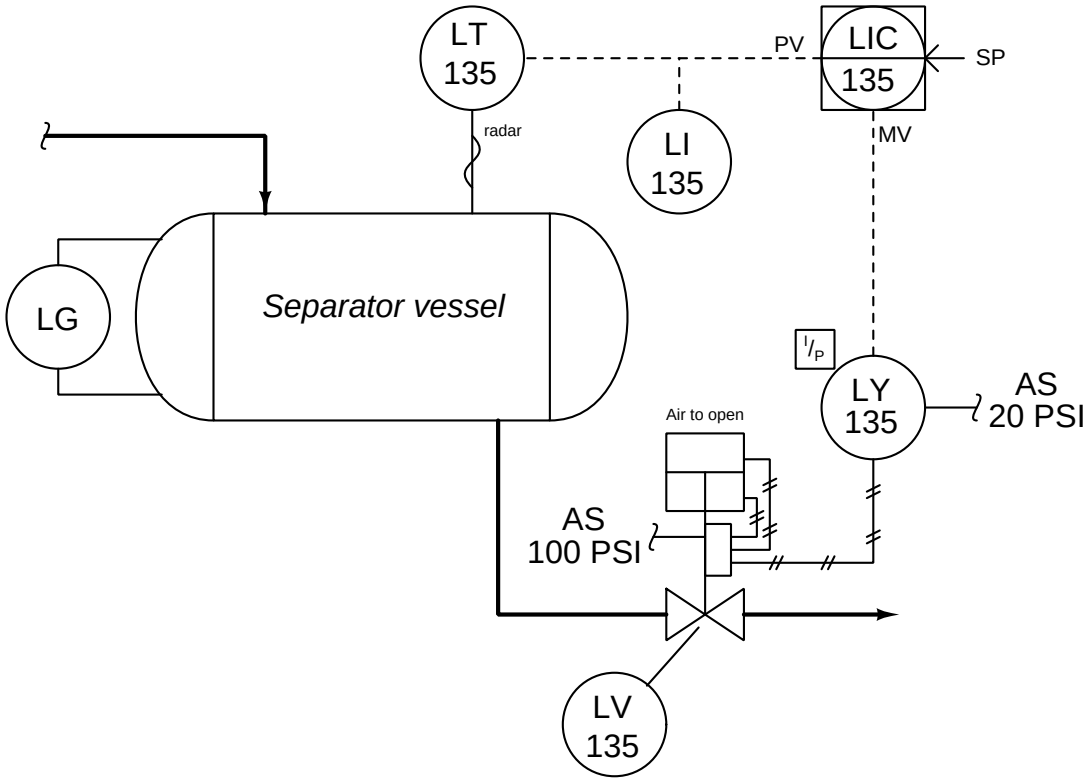
`Grading`

◯ [10%] (per correct answer)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

This separator tank liquid level control system has a problem – (*instructor describes here*):



The first thing you do is look at the position of the control valve, because it is located very close to the level gauge where you and the operator are standing. You can see that the control valve is _____.

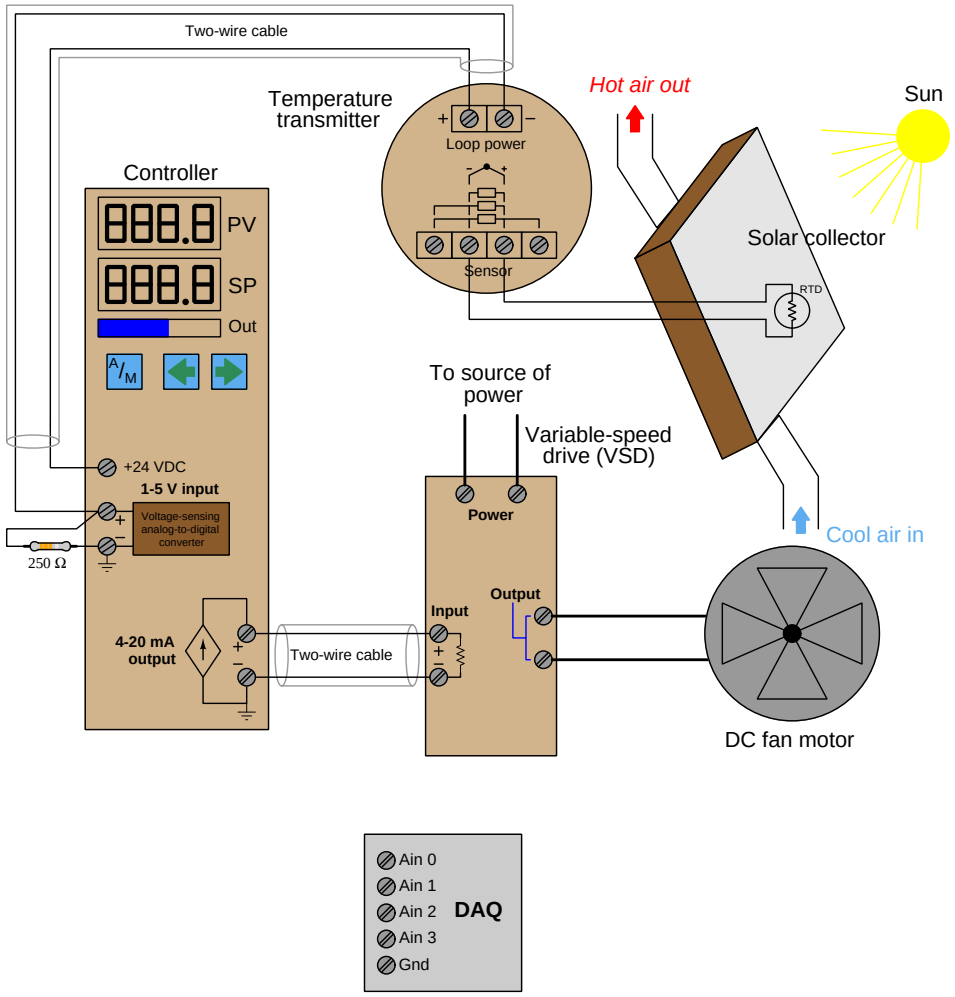
`Grading`

- ◯ [20%] Identify one possible fault that could account for all symptoms
- ◯ [20%] Identify another possible fault that could account for all symptoms
- ◯ [20%] Identify proper direction of action for the level controller (direct or reverse)
- ◯ [20%] Calculate proper LT-135 output signal (mA) for a liquid level of ____ and a calibrated range of 0 to 200 centimeters
- ◯ [20%] Calculate proper valve stem position (in percent) for an I/P transducer output of ____ PSI and valve calibrated range of 3 to 15 PSI

Note: full credit given only for answers that are correct <u>and</u> logically supported by trusted principles.

Problem #7

A researcher builds an experimental hot-air solar collector with a loop controller to maintain a constant interior temperature regardless of solar input:



The researcher also wishes to graph the temperature and fan command signals (PV and Output) using a data acquisition module (DAQ) connecting to a personal computer. The DAQ is capable of measuring DC voltage signals ranging from 0 to +7.5 Volts (single-ended, unipolar), like a four-channel DC voltmeter sharing a common negative terminal.

Sketch the necessary connecting wires to allow this DAQ unit to measure the temperature signal on input _____ and the fan command signal on input _____.

`Grading`

- ◯ [20%] Proper connections to DAQ input for temperature signal measurement
- ◯ [20%] Proper connections to DAQ input for fan command signal measurement
- ◯ [20%] Effect on solar collector temperature given a failure of _____
- ◯ [20%] Effect on solar collector temperature given a failure of _____
- ◯ [20%] Solar collector temperature if PV signal is ____ mA and range is +10 to +150 deg C

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #8

Examine the following Python script designed to control a programmable DC power supply and a benchtop digital multimeter, used to test a DC amplifier circuit's transfer function and output those test values in comma-separated variable format:

```
import pyvisa
res = pyvisa.ResourceManager()
res.list_resources()
VSRC = res.open_resource('USB0::0xF4EC::0x1410::T0103C22420252::INSTR')
VSRC.write("*RST")
METER = res.open_resource('USB0::0x2A8D::0xB318::MY59130016::INSTR')
METER.write("*RST")
x = 0.0
VSRC.write("CH1:VOLTage "+str(x))
VSRC.write("OUTPut CH1,ON")
print("Input voltage , Output voltage")
while (x <= 1.0):
  VSRC.write("CH1:VOLTage "+str(x))
  VSRC.write("OUTPut CH1,ON")
  y ,= METER.query_ascii_values("MEASure:VOLT?")
  print(x , " , " , y)
  x = x + 0.05
```

Grading

- ◯ [20%] Correct schematic diagram sketch showing these instruments connected to an noninverting opamp circuit with a voltage gain of ____
- ◯ [20%] Identify at least one essential feature lacking in the script as written
- ◯ [20%] Identify at least one "nice-to-have" feature lacking in the script as written
- ◯ [20%] Identify the number of steps in the voltage "sweep" performed by this script
- ◯ [20%] Modify this script to perform an "up-and-down" sweep test of the amplifier circuit rather than the unidirectional test it does now

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 60

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Identify typical instrument errors from data contained in an "As-Found" calibration table.
  zero, span, hysteresis, and linearity error characteristics, error percentage calculations

- (Question #2) Determine possible faults in a closed-loop control system using 4-20 mA signaling.
  4-20 mA signal scaling, Ohm's Law, Kirchhoff's Voltage Law, effects of opens versus shorts

- (Question #3) Identify effects of faults in a closed-loop feedback control system
  direct versus reverse controller action, negative feedback, typical instrument calibration errors, effects of liquid flow rates on process vessel liquid level, effects of heat input/output on process temperature, control valve failure modes

- (Question #4 – REVIEW) Determine possible faults in a combinational logic gate or relay ladder logic circuit.
  Logic function truth tables, properties of series and parallel networks, effects of opens vs. shorts, relay behavior

- (Question #5 – REVIEW) Determine PLC I/O statutes, bit statuses, and color-highlighting from process switch stimuli, schematic diagrams, and PLC ladder-logic code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch operation

file wt_0267