

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

NAME: _____

Last update 12 March 2024

Session	Topic	Prep.	Part.	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	Prep.	Part.	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	Prep.	Part.	Comments
Session 25	Intro to RF			
Session 26	Smith charts (I)			
Session 27	Vector network analyzers			
Session 28	Smith charts (II)			
Session 29	Frequency-shifting			
Session 30	Mixers			
Session 31	Fourier analysis			
Session 32	s -domain analysis (I)			
Session 33	s -domain analysis (II)			
Session 34	Passive filter transfer functions			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

NAME: _____

Session	Topic	Prep.	Part.	Comments
Session 37	Unit conversions			
Session 38	Sensors			
Session 39	Opamp review (I)			
Session 40	Opamp review (II)			
Session 41	Analog-digital conversion			
Session 42	Signal referencing and scaling			
Session 43	Opamp applications			
Session 44	Data acquisition			
Session 45	Advanced filter circuits			
Session 46	Phase-locked loops			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Prep.	Part.	Comments
Session 49	Metrology fundamentals			
Session 50	Electrical metrology standards			
Session 51	DC electrical metrology			
Session 52	Frequency and time			
Session 53	Automated testing			<i>INCOMPLETE</i>
Session 54	Discrete process control			<i>PENDING</i>
Session 55	Analog instrumentation circuits			<i>PENDING</i>
Session 56	PID control (I)			<i>PENDING</i>
Session 57	PID control (II)			<i>PENDING</i>
Session 58	PID control (III)			<i>PENDING</i>
Session 59	ORAL PRESENTATIONS			<i>PENDING</i>
Session 60	EXAM			<i>PENDING</i>

Essential information about this course:

- Learning to independently digest technical information and solve novel problems is even more important than learning electrical and electronic theory. To develop these skills we will *read* extensively to learn general principles, then tackle unfamiliar problems by logically applying those principles.
- This is a theory course, *but it is not lecture-based*. Pre-class reading assignments replace lecture, while class time is spent discussing the text and solving related problems.
- Thorough preparation for and full participation in every theory session are minimum expectations. Lack of preparation will result in point deductions, as will lack of participation and/or late arrival.
- Half of your course grade comes from “oral presentations” where you solve problems in full view of classmates and instructor just like during a technical job interview.
- Half of your course grade comes from written “mastery exams” where every question must be correctly answered to pass. Multiple re-tries are allowed on different exam versions, but only the first exam’s score counts toward your course grade.
- You should budget a minimum of 12 hours per week for this course, approximately 4 hours in-class and 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 before memorizing 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.

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 feedback control 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 control system circuits 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 feedback control 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)

Required Tools, Supplies, and Software

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

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

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

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

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

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

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

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

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

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

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

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

[file eet_tools](#)

Grading standards for 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)
- Unpreparedness for theory sessions = -1% per session
- Non-participation for theory sessions = -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 and then spend the entire class time discussing what was learned, what didn’t make sense, 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).

Scoring for theory sessions is based on your preparation for and participation within each theory session. These scores are subtractive rather than additive; that is to say, arriving fully prepared and participating fully in each group discussion contributes nothing toward the course grade, but unpreparedness and/or non-participation detracts from the course grade. Showing up on time, fully prepared, and genuinely contributing to every activity is the *minimum* expectation for a any professional career, and so this is the standard maintained in this course. Failure to arrive on time to a theory session, or arriving with incomplete preparatory work for that session results in a -1% deduction per session to your course grade. Satisfactory preparation is defined as a good-faith effort to complete all pre-work specified in the theory session plan. Note that this does *not* mean mastery of that session’s concepts, but simply a presentation of your best work. Failure to positively and proactively contribute to the discussion during a theory session similarly results in a -1% deduction per session. Half-point deductions are awarded for being *mostly* but not *fully* prepared/engaged.

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 theory session preparation, submission of all assigned work (e.g. reading outline and reflections, attempted answers and work for all assigned questions) before the scheduled start time of that theory session will count as full credit. This shows your good-faith effort in preparing for the discussion.
- For theory session participation, correctly answering five questions from the Introduction chapter of the assigned learning module specifically focusing on new concepts (not review) will substitute for dialogue and problem-solving with classmates and instructor. Correctness is graded here in order to ensure you understand the day’s topic.

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.

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 of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another’s work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

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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, outline, and reflect on the “Growing Your Career” chapter of the *Career Guide* document
- Read, outline, and reflect 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 time and effort necessary to succeed in this program:
 - Full load = 12 credits = 36 hours/week total time commitment + *General Education courses!*
 - Make *daily contact* with instructor, even if absent
 - Exert *honest effort* to solve every problem before asking for help
 - *Self-start* when faced with challenges and take ownership of your education
 - Never *procrastinate*, as this guarantees failure
- [Optional] – sign FERPA release forms
- Experiment with Python programming together as a class

Forms provided by the instructor for today’s session:

- FERPA release form
- IETTI-223 Theory course document (printed from cover page through Theory Session 2)
- IETTI-225 Experiments course document (only if you are enrolled in this course as well)
- IETTI-236 Projects course document (only if you are enrolled in this course as well)

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/index#courses>, links to all IETTI course documents
- <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, stored as a folder on the Desktop of every computer in the lab

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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, outline, and reflect on the following section of the Tutorial chapter:
→ Bitwise operators
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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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, outline, and reflect on the Tutorial chapter in its entirety.
- Read, outline, and reflect on the Simple four-bit ALU section of the Derivations and Technical References chapter.
- Read, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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 outline 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.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the following sections of the Tutorial chapter:
→ A simple computer example
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the following sections of the Tutorial chapter:
 - Machine code and assembly language
 - Interrupts
- Read, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the Tutorial chapter in its entirety.
- Locate a datasheet for a modern programmable logic IC and prepare to share the following information about it:
 - Power supply voltage limits
 - Number of I/O pins available
- Complete “Multiplexer-based logic functions” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Two multiplexers creating a logic function” 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the following sections of the Tutorial chapter:
 - Pointers
 - Arrays
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0251

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. You are allowed to bring notes for reference, but not allowed to read them to your 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. 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, 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.

Section #1 – 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 *STSTB* signal

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

Section #2 – 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 #3 – 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 #4 – 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 #5 – 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 #6 – 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

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the following sections of the Tutorial chapter:
 - Flow control
 - Channel arbitration
 - The OSI Reference Model
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the Tutorial chapter in its entirety.
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0136

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, outline, and reflect on the SPI bus (Serial Peripheral Interface) section of this document, and answer the following questions:
 - What are the various lines in an SPI network named, and what is each of their functions?
 - How are specific “slave” devices selected by the “master” device in an SPI network?
 - What is the “critical edge” in an SPI system, and how do the four different SPI modes help define it?
 - How are data frames started and ended in an SPI network?
 - One of the advantages of SPI is that the hardware is very simple, each device containing a simple shift register for SPI data transfer. Explain how shift registers are used within an SPI network to facilitate data transfer.
- Read, outline, and reflect on the I²C bus (Inter-Integrated Circuit) section of this document, and answer the following questions:
 - How does I²C differ from SPI?
 - What are the various lines in an I²C network named, and what is each of their functions?
 - How are specific “slave” devices selected by the “master” device in an I²C network?
 - How are data frames started and ended in an I²C network?
 - How is a successful I²C data transaction acknowledged by the receiving device?
 - What factors dictate the sizing of pull-up resistors in an I²C 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the Tutorial chapter in its entirety.
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Interpreting an 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0168

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. You are allowed to bring notes for reference, but not allowed to read them to your 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. 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").

Foundational Concepts

The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	R vs. X vs. Z
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's Voltage Law	Behavior of transformers
Kirchhoff's Current Law	Properties of wye networks
Maximum Power Transfer Theorem	Properties of delta networks
Superposition Theorem	Heat transfer
Thévenin's and Norton's Theorems	Pulse-width modulation
Electric fields and capacitance	Transmission lines
Magnetic fields and inductance	Serial data communication concepts
Inverse-exponential growth/decay	
Conduction in semiconductors	
Behavior of PN junctions	
Behavior of BJTs	
Behavior of FETs	
Sinking vs. sourcing current	
Behavior of thyristors	
Switch/gate circuits and Boolean	
Switch/gate circuits and truth tables	
Logic voltage levels	
DeMorgan's Theorem	

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.

Problem #1

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.

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 #2

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 #3

Sketch three different signal waveforms all encoding the same sequence of binary bits (_____ 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.

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 #4

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.

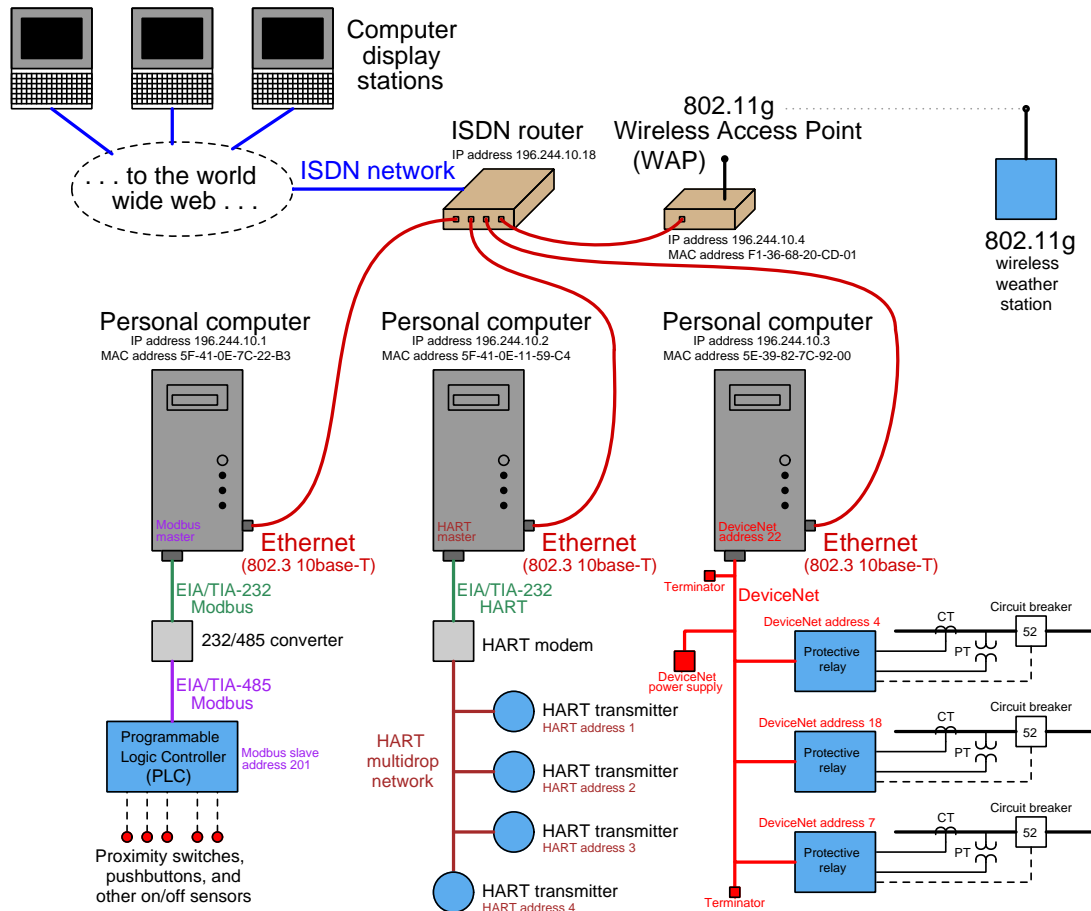
Grading

- ☐ [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 #5

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 #6

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 and 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 polarization, MTU and RTU nodes, arbitration protocols, simplex versus half-duplex communication, RF link budget concepts
- (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) Identify a passive filter circuit characteristic from its schematic diagram, and predict the effects of a component fault on that characteristic.
Properties of series networks, properties of parallel networks, effects of opens vs. shorts, filter circuit behavior, capacitive reactance, inductive reactance
- (Question #7 – REVIEW) Evaluate digital timing diagrams for adequate signal integrity.
Timing diagrams, AC quantities, switch bounce, oscilloscope display interpretation, eye diagram interpretation, resonance, propagation delay, set-up time, hold time, logic levels in TTL and CMOS circuits.
- (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

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0256

Theory session 26

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0259

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, outline, and reflect 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* 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?
- 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):
 - User calibration
 - Resistor, capacitor, inductor testing

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0252

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, outline, and reflect 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 Qualitative 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 values for this transceiver’s LNA (Low-Noise Amplifier) as shown on a Smith Chart
 - Identify the range of optimum load impedance values 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0260

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, outline, and reflect on the following section of the Tutorial chapter:
→ Frequency-shifting
- Read, outline, and reflect on the Heterodyne radio reception section of the Historical References chapter.
 - Explain why “*some type of frequency transformation or lowering must be used*” according to the author for the communication of Morse-code pulse signals via radio.
 - If the desired radio signal to receive was 100000 Hz and the local oscillator (“generator”) was set to output 100500 Hz, what would the resulting audio tone frequency be whenever the signal was received?
 - If the desired radio signal to receive was 100000 Hz but there was an interfering signal of 105000 Hz from some other transmitter, and the local oscillator (“generator”) was set to output 100500 Hz, what would the resulting audio tone frequencies be for the two different Morse-code telegraph signals?
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0237

Theory session 30

Source text – *Mixers* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Mixer applications
 - Multiplicative mixing
 - Non-ideal mixing
- Complete “Frequency adjustment on a mixer input” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Output frequency predictions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “The image problem” in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0175

Theory session 31

Source text – *Frequency-Domain Analysis* learning module

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

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

- Read, outline, and reflect on the following sections of the Full Tutorial chapter:
 - Fourier's Theorem
 - Fourier series
 - Filter-based Fourier analysis
 - Mixer-based Fourier analysis
 - Fourier analysis of a square wave
 - A digital Fourier transform algorithm
- Complete “Multi-harmonic analyzer” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Fourier analysis of a triangle wave” in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0257

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, outline, and reflect on the following sections of the Tutorial chapter:
 - Impedance review
 - Natural frequency, reactance, and impedance
 - Complex frequency and impedance
- Complete “Exploring Euler’s Relation” in the Quantitative Reasoning section of the Questions chapter.
- Complete “RC network impedances” in the Quantitative Reasoning section of the Questions chapter.
- Complete “LR 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0280

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, outline, and reflect on the following sections of the Tutorial chapter:
 - Transfer functions
 - AC network transfer function examples
- Complete “Explain this joke” 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0281

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?

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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

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file wt_0282

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. You are allowed to bring notes for reference, but not allowed to read them to your 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. 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").

Foundational Concepts

The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	R vs. X vs. Z
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's Voltage Law	Behavior of transformers
Kirchhoff's Current Law	Properties of wye networks
Maximum Power Transfer Theorem	Properties of delta networks
Superposition Theorem	Heat transfer
Thévenin's and Norton's Theorems	Pulse-width modulation
Electric fields and capacitance	Transmission lines
Magnetic fields and inductance	
Inverse-exponential growth/decay	
Conduction in semiconductors	
Behavior of PN junctions	
Behavior of BJTs	
Behavior of FETs	
Sinking vs. sourcing current	
Behavior of thyristors	
Switch/gate circuits and Boolean	
Switch/gate circuits and truth tables	
Logic voltage levels	
DeMorgan's Theorem	
Signal mixing and modulation	
Smith charts	
Transfer functions	

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.

Problem #1

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

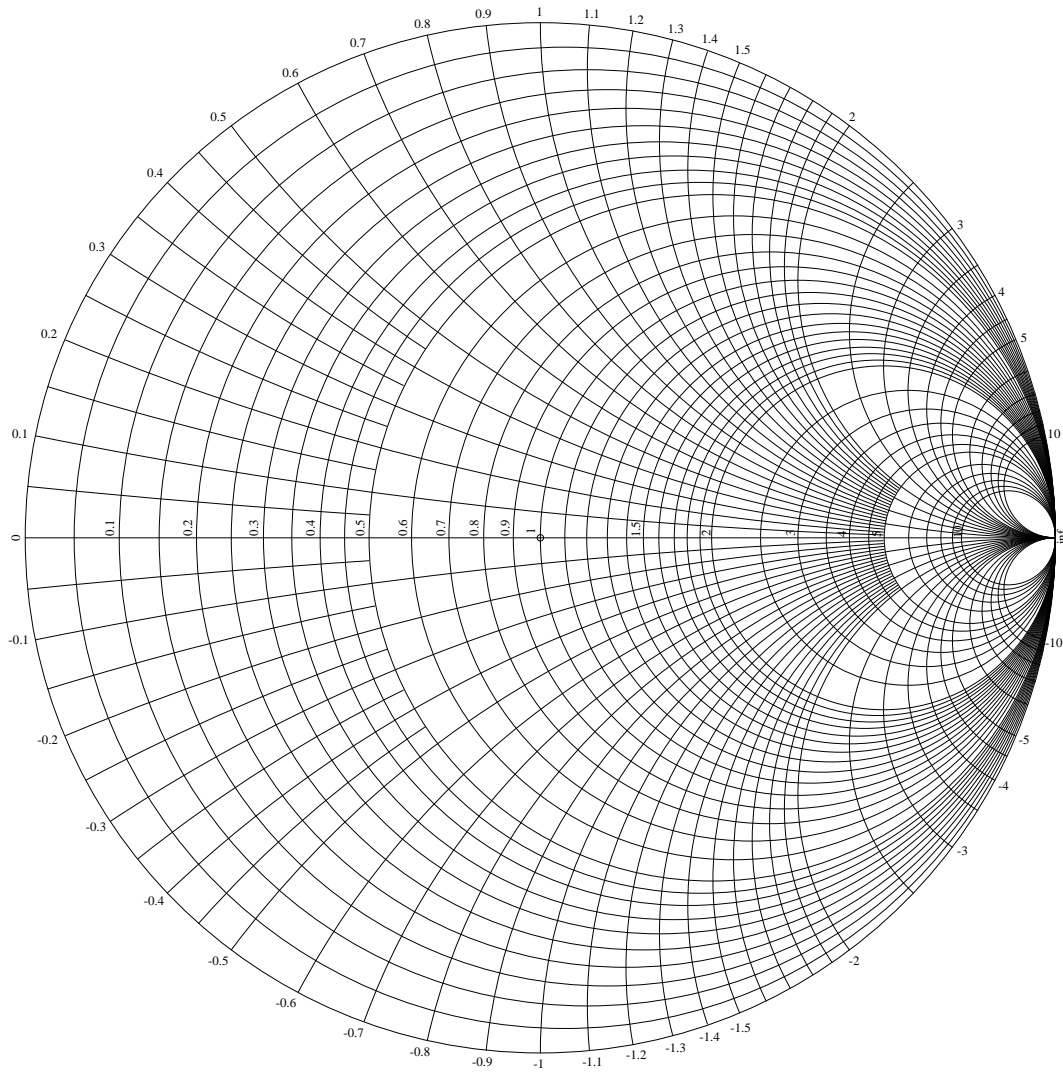
- ☐ [20%] Correct analog modulated signal
- ☐ [20%] Correct digital modulated signal
- ☐ [20%] Describe an analog baseband signal that would only contain odd harmonics
- ☐ [20%] Describe an analog baseband signal that would contain both odd and even harmonics
- ☐ [20%] Identify pros and cons of AM versus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

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

Problem #2

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



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 #3

Modify this C-language computer program to perform a frequency-sweep test on the circuit shown below, 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 Zl, Zc, Zt;
    for (f = f_start ; f <= f_end ; f = f + 1e6)
    {
        Zl = I * 2 * M_PI * f * L;
        Zc = -I * (1.0 / (2 * M_PI * f * 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; }
```

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 simulation assuming _____ fails (*open/shorted*)

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

Problem #4

Modify this Python-language computer program to perform a frequency-sweep test on the circuit shown below, 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):
    Zl = complex(0, 2*pi*f*L)
    Zc = complex(0, -1.0/(2*pi*f*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
```

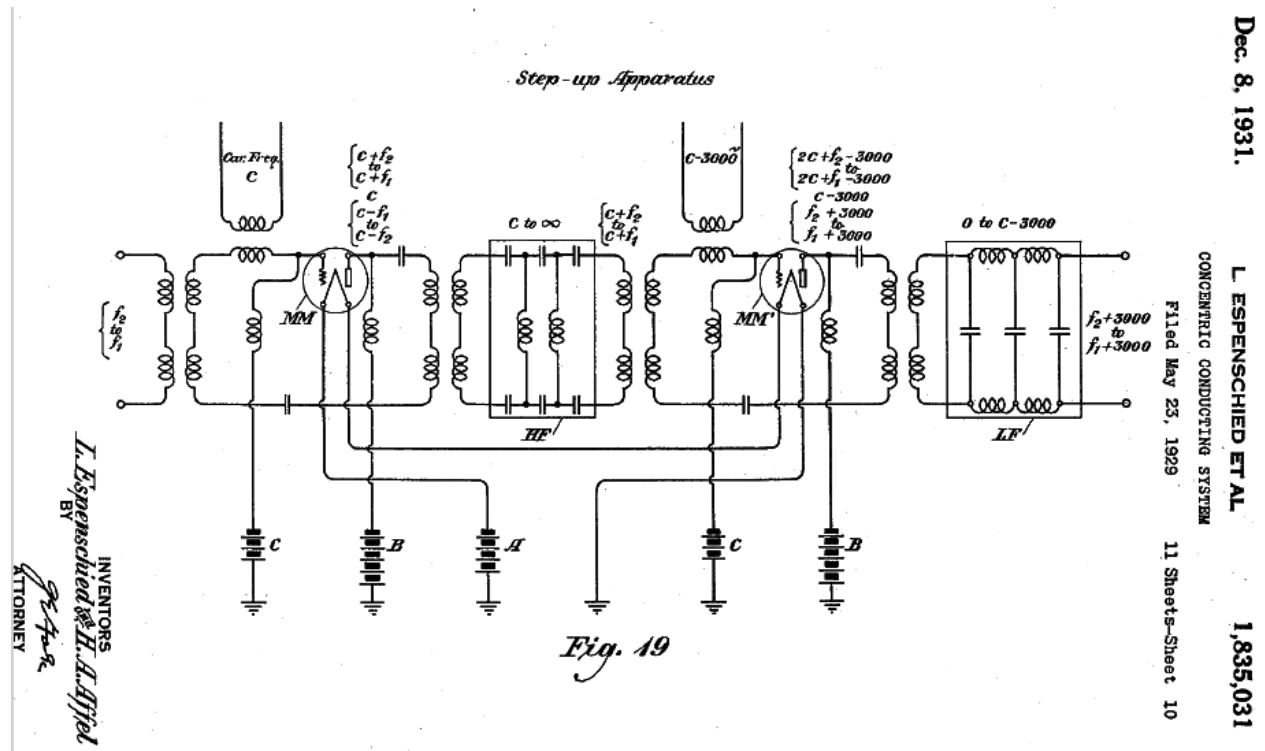
Grading

- ☐ [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 simulation assuming _____ fails (*open/shorted*)

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

Problem #5

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 = _____

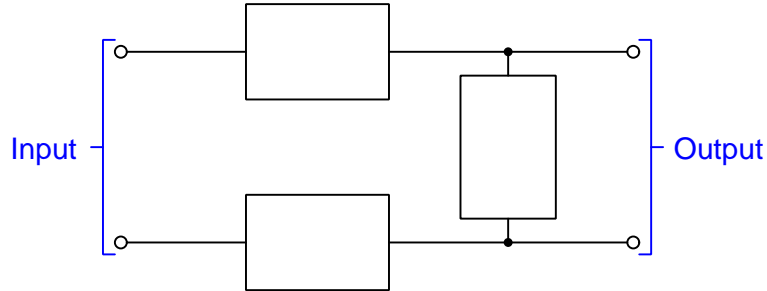
Grading

- ☐ [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 #6

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.

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) 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

Theory session 37

Source text – *Matter and Energy* learning module

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

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

- Read, outline, and reflect on the following section of the Tutorial chapter, especially focusing on the “Unity fractions” subsection:
→ Unit conversions and physical constants
- Complete “Analog-digital converter signals” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Pressure unit conversions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Flow rate conversion” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Frequency conversions” in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0263

Theory session 38

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, outline, and reflect on the following sections of the Tutorial chapter. Feel free to *skip* all subsections dealing with chemical sensors:
 - Potentiometric sensors
 - Amperometric sensors
 - Resistive sensors
- 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.
- **Coding challenge** – write a simple computer program in a text-based language to simulate voltages in a four-resistor Wheatstone bridge circuit, capable of showing both balanced and unbalanced conditions.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0146

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 “Electronic levers” in the Conceptual Reasoning section of the Questions chapter.
- 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.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0283

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:
 - 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0272

Theory session 41

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, outline, and reflect on the following sections of the Tutorial chapter:
 - ADCs and DACs
 - Resolution
 - ADC sampling and aliasing
- 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.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
file wt_0059

Theory session 42

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0152

Theory session 43

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, outline, and reflect 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0276

Theory session 44

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, outline, and reflect on the Tutorial chapter in its entirety.
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0153

Theory session 45

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, outline, and reflect 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
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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 46

Source text – *Phase-Locked Loops* learning module

Source text – *CD4046B Phase-Locked Loop...*, written by David K. Morgan

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

EET Reference collection – EETREF/Application_Notes/TI_CD4046B_phase_locked_loop*.pdf

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

- Read, outline, and reflect 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.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0261

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. You are allowed to bring notes for reference, but not allowed to read them to your 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. 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.

Problem #1

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.

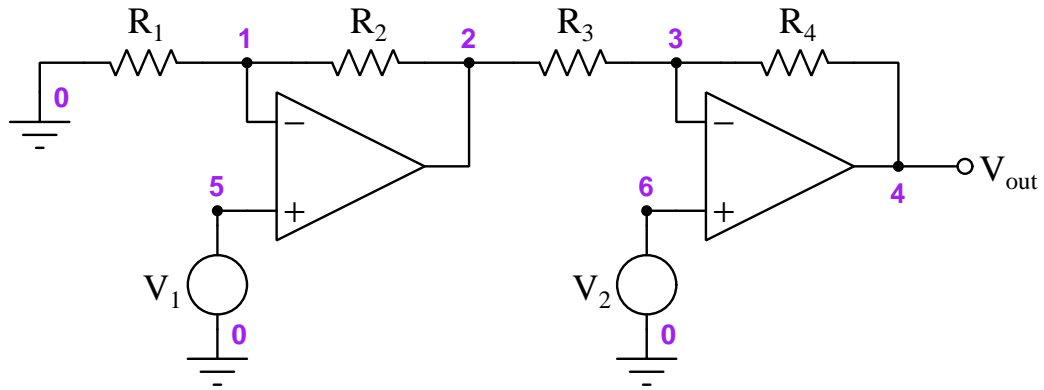
Grading

- ☐ [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 #2

(Component values randomly chosen by instructor):



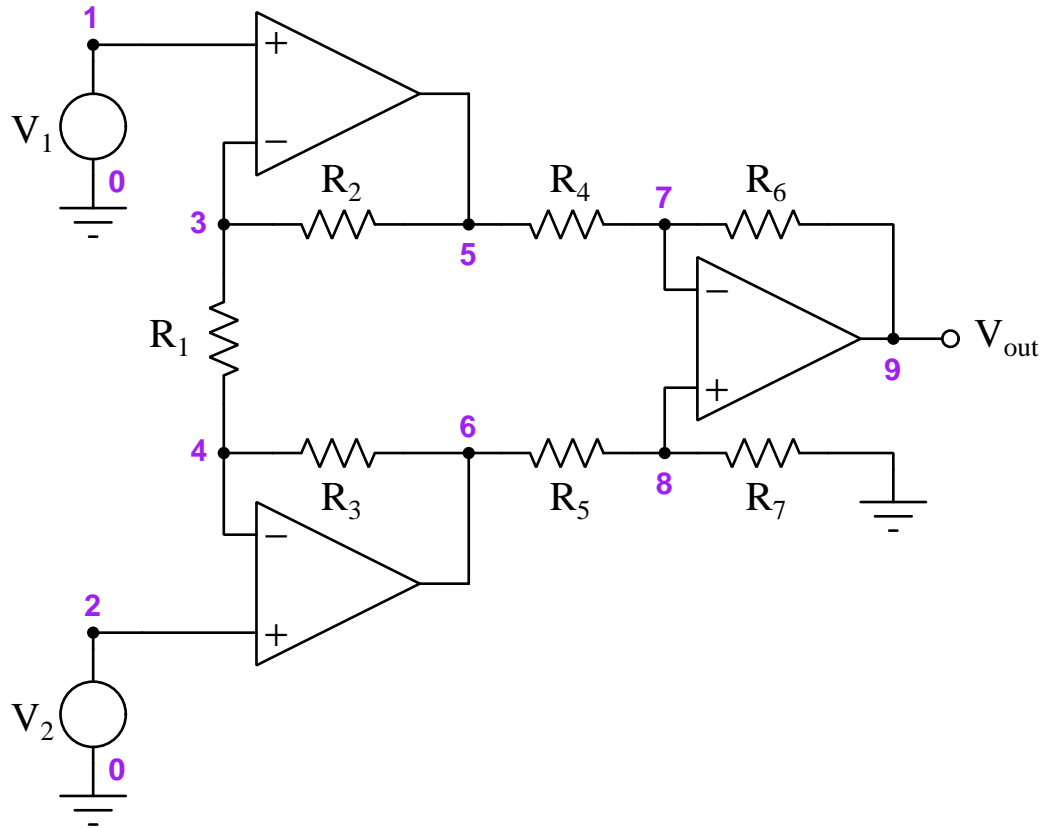
Grading

- ☐ [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 3
- ☐ [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 #3

(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 #4

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 #5

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 _____.

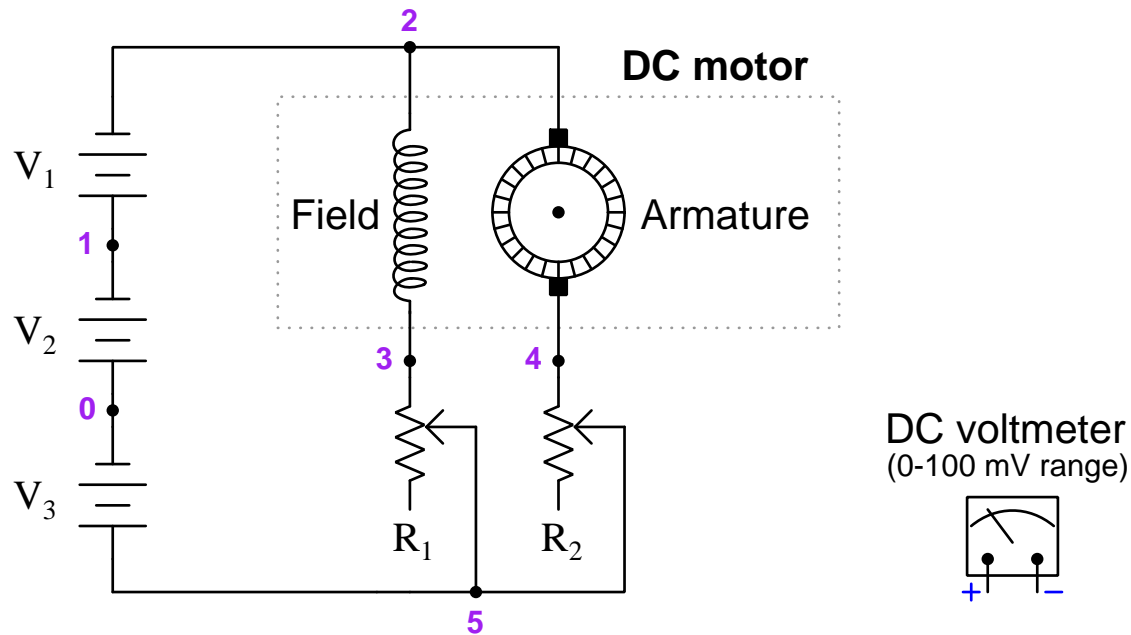
Grading

- ☐ [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 #6

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 armature and 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 #7

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
- (Question #2) Convert from one physical measurement into another of differing unit(s).
Unity fraction technique, dimensional analysis
- (Question #3) 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
- (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 temperatures, voltages, currents, and/or power dissipations for a power semiconductor component heat sink given all the necessary parameters.
Thermal resistance, Joule's Law
- (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

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, outline, and reflect 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
- Complete “Clock accuracy” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Thermometer calibration results” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Voltmeter calibration results” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Ammeter calibration results” in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0268

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, outline, and reflect on the following section of the Tutorial chapter:
→ Electrical metrology 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.
- Locate datasheet(s) for precision oscillator ICs and compare in terms of cost, supply voltage, stability, and absolute accuracy.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect 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 Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

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, outline, and reflect on the following section of the Tutorial chapter:
 - Frequency and time metrology standards
- 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?
- 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:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0287

Theory session 53

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, outline, and reflect 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
- Complete “???” in the Conceptual Reasoning section of the Questions chapter.
- Complete “???” in the Quantitative Reasoning section of the Questions chapter.
- Complete “???” in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0288

Theory session 54

Source text – ??? learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_???pdf

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

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0002

Theory session 55

Source text – ??? learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_???.pdf

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

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0002

Theory session 56

Source text – ??? learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_???.pdf

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

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0002

Theory session 57

Source text – ??? learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_???.pdf

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

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0002

Theory session 58

Source text – ??? learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_???.pdf

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

Theory Session Expectations:

Summarize the assigned text(s) in your own words, including descriptions of mathematical analyses, thought experiments, analogies, and other devices employed by the author, as well as thoughts of your own. Contribute positively to the dialogue, and if you are confused at any point the minimum expectation is to ask thoughtful questions. The instructor will assess your preparatory work and contributions for good-faith effort.

Expect the instructor to question your reasoning and challenge your answers, even when correct! Base your answers on the laws, properties, and other foundational principles learned previously. The instructor will challenge you to pay attention to detail, examine assumptions, and apply sound reasoning.

file wt_0002

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. You are allowed to bring notes for reference, but not allowed to read them to your 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. 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").

Foundational Concepts

The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	R vs. X vs. Z
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's Voltage Law	Behavior of transformers
Kirchhoff's Current Law	Properties of wye networks
Maximum Power Transfer Theorem	Properties of delta networks
Superposition Theorem	Heat transfer
Thévenin's and Norton's Theorems	Pulse-width modulation
Electric fields and capacitance	Transmission lines
Magnetic fields and inductance	
Inverse-exponential growth/decay	
Conduction in semiconductors	
Behavior of PN junctions	
Behavior of BJTs	
Behavior of FETs	
Sinking vs. sourcing current	
Behavior of thyristors	
Switch/gate circuits and Boolean	
Switch/gate circuits and truth tables	
Logic voltage levels	
DeMorgan's Theorem	

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.

Problem #1

(Component values randomly chosen by instructor):

(Under development)

Grading

- ☐ [20%] Current magnitude and direction through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude and direction through node ? ($I_?$)
- ☐ [20%] All current magnitudes and directions entering and exiting node ?
- ☐ [20%] Voltage magnitude and polarity between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Voltage magnitude and polarity across resistor $R_?$ ($V_{R?}$)

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

Problem #2

(Component values randomly chosen by instructor):

(Under development)

Grading

- ☐ [20%] Current magnitude and direction through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude and direction through node ? ($I_?$)
- ☐ [20%] All current magnitudes and directions entering and exiting node ?
- ☐ [20%] Voltage magnitude and polarity between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Voltage magnitude and polarity across resistor $R_?$ ($V_{R?}$)

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

Problem #3

(Component values randomly chosen by instructor):

(Under development)

Grading

- ☐ [20%] Current magnitude and direction through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude and direction through node ? ($I_?$)
- ☐ [20%] All current magnitudes and directions entering and exiting node ?
- ☐ [20%] Voltage magnitude and polarity between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Voltage magnitude and polarity across resistor $R_?$ ($V_{R?}$)

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

Problem #4

(Component values randomly chosen by instructor):

(Under development)

Grading

- ☐ [20%] Current magnitude and direction through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude and direction through node ? ($I_?$)
- ☐ [20%] All current magnitudes and directions entering and exiting node ?
- ☐ [20%] Voltage magnitude and polarity between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Effect on output signal if ____ fails (*open* or *shorted*)

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

Problem #5

(Component values randomly chosen by instructor):

(Under development)

Grading

- ☐ [20%] Current magnitude and direction through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude and direction through node ? ($I_?$)
- ☐ [20%] All current magnitudes and directions entering and exiting node ?
- ☐ [20%] Voltage magnitude and polarity between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Voltage magnitude and polarity across resistor $R_?$ ($V_{R?}$)

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

Problem #6

Predict the effects of resistor _____ failing (*open/shorted*), assuming the switch is in the (*open/closed*) position when the fault occurs:

(Under development)

Grading

- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor $R_?$ ($I_{R?}$)
- ☐ [20%] Voltage magnitude variation (increase/decrease/same) between nodes ? and ? ($V_{?-?}$)
- ☐ [20%] Voltage magnitude variation (increase/decrease/same) across resistor $R_?$ ($V_{R?}$)

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
- (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 statuses, 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