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### Session Plan

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### Essential Information about this Course:

- Learning to independently digest technical information and solve novel problems is more important than learning electrical and electronic theory. To develop these skills we will read extensively to learn general principles, write to document and consolidate our understanding of those principles, and practice solving problems using 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.

- Late arrival to class, failing to summarize the assigned reading in your own words, and/or unattempted problems will result in point deductions.

- 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 rather than memorize procedures.
Values

This educational program exists for one purpose: to empower you with a comprehensive set of knowledge, skills, and habits to unlock opportunities in your chosen profession. The following values articulate personal attitudes guaranteed to fulfill this purpose, and the principles upon which this program is designed. They embody what I like to call a *strong learning ethic*, similar to a strong work ethic but applied to the learning process rather than a job.

**Ownership** – you are the sole proprietor of your education, of your career, and to a great extent your quality of life. No one can force you to learn, make you have a great career, or grant you a fulfilling life – these accomplishments are possible only when you accept responsibility for them.

**Responsibility** – *ensuring* the desired outcome, not just *attempting* to achieve the outcome. Responsibility is how we secure rights and privileges.

**Initiative** – independently recognizing needs and taking responsibility to meet them.

**Integrity** – living in a consistently principled manner, communicating clearly and honestly, applying your best effort, and never trying to advance at the expense of others. Integrity is the key to trust, and trust is the glue that binds all relationships personal, professional, and societal.

**Perspective** – prioritizing your attention and actions to the things we will all care about for years to come. Never letting short-term concerns eclipse the long-term.

**Humility** – no one is perfect, and there is always something new to learn. Making mistakes is a symptom of living, and for this reason we need to be gracious to ourselves and to others.

**Safety** – assessing hazards and avoiding unnecessary risk to yourself and to others.

**Competence** – your ability to consistently and independently apply knowledge and skill to the solution of practical problems. Competence includes the ability to verify the appropriateness of your solutions and the ability to communicate so that others understand how and why your solutions work.

**Diligence** – exercising self-discipline and persistence in learning, accepting the fact there is no easy way to absorb complex knowledge, master new skills, or overcome limiting habits. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all documentation complete, and all root-causes of problems identified and corrected.

**Community** – your actions impact other peoples’ lives, for good or for ill. Conduct yourself not just for your own interests, but also for the best interests of those whose lives you affect.

**Respect** is the acknowledgment of others’ intrinsic capabilities, responsibilities, and worth. Everyone has something valuable to contribute, and everyone deserves to fully own their lives.
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)

• Summarize physical laws and concepts related to the aforementioned circuit types, acquired from technical literature, and clearly present them in both written (journal) and oral formats. (Addresses Program Learning Outcomes 1, 6, 7)
Required Tools, Supplies, and Software

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

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

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**Required Tools, Supplies, and Software**

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

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

**Multimeter** — this is your first and most important electronic test instrument. At minimum it must measure DC and AC voltage, DC and AC current (milliAmpere range), resistance, and “diode check” voltage drop. Cost is a strong function of accuracy, additional features, frequency range, and safety (“Category” ratings for over-voltage exposure). The Fluke model 87-V is an excellent professional-grade choice for digital multimeters, and the Simpson 260 is an excellent professional-grade choice for analog multimeters. The best **minimal-cost** multimeter I’ve found is the model DT-830B which sells for less than $20, with the test leads being the weakest component (but easily upgraded).

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

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

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

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

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

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

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

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

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

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

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

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

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.
Theory session 01

Source text – Career Guide learning module

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

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

Source text – Introduction to Python Language Programming learning module

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 commitment: a minimum of 3 hours per week per enrolled credit is necessary for success!
- [Optional] – sign FERPA release forms
- Experiment with Python programming together as a class
- [Recommended] – be available to give advice to the new students this semester!

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

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Bitwise operators
- 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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Digital building-blocks
  → Putting it all together – the processor

- Prepare to explain to your classmates and to your instructor the sequence of operations described in the Putting it all together – the processor Tutorial section, as this gives a very detailed view of how a typical microprocessor fetches and executes instructions. *If you have questions about this, be sure to write those in your Theory Journal for quick reference during class!*

- Complete “Intel 8080 architecture” in the Conceptual Reasoning section of the Questions chapter.

- Complete “Intel 8080 processor cycles” in the Conceptual Reasoning section of the Questions chapter.

- Complete “Early microprocessor timing diagram” in the Conceptual Reasoning section of the Questions chapter.

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to *apply* them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - A simple computer example
- Complete “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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - Pointers
  - Arrays
- 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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Theory session 11

Oral Presentations

Today’s class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. 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.
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.*
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*
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Theory session 14

**Source text** – *Serial Data Communication* learning module


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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - Flow control
  - Channel arbitration
  - The OSI Reference Model
- 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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to *apply* them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete “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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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.

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
- 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.

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

- Read, reflect, and update your Theory Journal on the I²C bus (Inter-Integrated Circuit) section of the Texas Instruments reference 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete “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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete “Interpreting 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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - Fiber optic data communication
  - Fiber optic cable construction
  - Multi-mode and single-mode optical fibers
  - Fiber optic connectors and routing
  - Fiber optic safety

- 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
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”).

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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:

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

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

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

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

- (Question #9 – REVIEW) Determine the length of a transmission line given reflectometry data, or vice-versa. *Velocity factor, speed of light, oscillograph display interpretation, conversions between metric and imperial units of length*
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  -> Characteristics of RF
  -> Skin effect
  -> Balanced versus unbalanced signals
  -> RF cabling
  -> RF connectors
  -> PCB layout for high frequencies
  -> Near-field testing
  -> RF safety

- Examine and reflect on the Example: near-field probing inside a PC section of the Case Tutorial chapter, and answer the following questions:
  -> What useful information may we discern from these near-field probing examples?
  -> Why does the H-field probe provide such different results when positioned differently over the PCB?

- Locate the datasheet for the Texas Instruments model TRF37A73 RF amplifier (document SLASE39, dated May 2014) and answer the following questions based on information within the document:
  -> Is the RF input to this amplifier balanced or unbalanced?
  -> Is the RF output from this amplifier balanced or unbalanced?
  -> Why does it matter that both the amplifier’s input and output are “matched” to a value of 50 Ohms?
  -> Explain the rationale for the PCB layout guidelines specified in this document.

- Locate the datasheet for the Texas Instruments model CC2591 RF front end (document SWRS070B, revised September 2014) and answer the following questions based on information within the document:
  -> Is the antenna signal connection to this amplifier balanced or unbalanced?
  -> How much receiver gain does this IC provide?
  -> How much transmitter output power does this IC provide?

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Frequency-shifting

- Examine and reflect on the Example: balanced mixer frequencies section of the Case Tutorial chapter, and answer the following questions:
  → Explain how each of the frequencies in the output signal may be calculated from the input frequencies
  → Sketch a frequency-domain plot for any of the given examples

- Read, reflect, and update your Theory Journal 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Theory session 27

Source text – Smith Charts learning module


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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial in its entirety and answer the following questions:
  - What differentiates a VNA from test equipment such as a signal generator, an oscilloscope, or a spectrum analyzer?
  - Identify the components within the “RF Front-End” block diagram (figure 4), and explain how a VNA could be useful in testing each of those components.
  - What are S-parameters 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Impedance and admittance Smith Charts
  → Series-parallel analysis using Smith Charts

- Examine and reflect on the Example: frequency-sweeps of RLC network impedances section of the Case Tutorial chapter, and answer the following questions:
  → For each of the curves plotted, identify which end of the curve represents the low-frequency end of the sweep test and which end represents the high
  → Explain why, as best you can, each curve has the shape it does based on the topology of its respective network (e.g. series, parallel, series-parallel)

- Complete “Smith Chart test of a dipole antenna” in the 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Impedance review
  → Natural frequency, reactance, and impedance
  → Complex frequency and impedance
  → s variable summary
- Complete “RC network impedances” in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to perform calculations for any of the assigned questions or examples found in the Tutorial.

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

« file wt 0280 »
Theory Session 31

Source text – *The S variable* learning module


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

- Complete “LR network impedances” in the Quantitative Reasoning section of the Questions chapter.
- Complete “RLC network impedances” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Determining s from oscillographs” in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to *apply* them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Summarize in your own words the following concepts:
  - $s$ variable
  - Angular velocity or natural frequency
  - Neper velocity
  - Transfer function
  - Pole
  - Zero
  - Bode plot
  - Time constant
  - Any non-electrical applications of transfer functions you know of

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

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
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:

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

*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:

```c
#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 \( Z_{\text{total}} \) at starting frequency verified by manual calculations
- [10%] Correct simulated \( Z_{\text{total}} \) 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:

```python
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:

\[
\begin{align*}
    f_1 &= \text{Lowest frequency contained in the audio signal band} = \\
    f_2 &= \text{Highest frequency contained in the audio signal band} = \\
    c &= \text{Carrier frequency} = \\
\end{align*}
\]

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:

![Network Diagram]

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

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter, 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter. Feel free to skip all subsections dealing with chemical sensors:
  - Signals, sensors, and switches
  - Potentiometric sensors
  - Amperometric sensors
  - Resistive sensors

- 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to *apply* them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - ADCs and DACs
  - Resolution
  - ADC sampling and aliasing
  - DAC circuitry: binary-weighted
  - DAC circuitry: R-2R
  - ADC circuitry: flash conversion
  - ADC circuitry: tracking conversion
  - ADC circuitry: successive approximation conversion

- 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Amplification with offset

- Complete “Opamp signal scaling circuits” in the Quantitative Reasoning section of the Questions chapter.

- Complete “Constant-current electronic load circuit” in the Quantitative Reasoning section of the Questions chapter.

- Sketch a design for an electronic load circuit capable of performing more than one function (e.g. one mode for constant-current, another for constant-voltage). Make this design as complete as you can, with component part numbers, necessary heat-sinking, etc.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete “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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - Basic filter networks
  - Output-limited filter networks
  - Balanced versus unbalanced filter networks
  - Filter network topology
  - Improving roll-off
  - Passive filter design

- 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:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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.

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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?

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:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to *apply* them and to recover from mistakes when they occur.
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

0 [20%] Identify the type of filter (low-pass, high-pass, band-pass, or band-stop)
0 [20%] Correct (unsimplified) transfer function
0 [20%] Correct (simplified to have no compound fractions) transfer function
0 [20%] Correct identification of zero(es)
0 [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:

```c
#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 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.*

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - What is metrology?
  - Metrological standards
  - Measurement terminology
  - Measurement uncertainty
  - Proportionate expressions
  - Typical instrument errors
  - Drift and instability

- Complete “Clock accuracy” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Thermometer calibration results” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “Voltmeter calibration results” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “Ammeter calibration results” in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following subsections of the Tutorial chapter:
  - Electrical metrology standards – DC voltage standards
  - Electrical metrology standards – Resistance standards
  - Electrical metrology standards – DC current standards

- Locate technical literature for a Fluke model 5730A multifunction calibrator and identify the following information within the document(s):
  - How much warm-up time is required when turning it on for the first time in a long while? Why do you think this time is necessary?
  - What are some of the auxiliary amplifier options for this unit, and what do they do?
  - Uncertainty specifications for this instrument’s output functions – how unstable and/or uncertain are some of the specifications?

- Locate datasheet(s) for precision voltage reference ICs and compare in terms of cost, supply voltage, stability, and absolute accuracy.

- Locate datasheet(s) for precision oscillator ICs and compare in terms of cost, supply voltage, stability, and absolute accuracy.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - Precision voltage measurement techniques
  - Precision resistance measurement techniques
  - Electrical metrology tools
- Complete “EKG monitor” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Kelvin-Varley voltage divider” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Testing a 250 V meter with a 10 V standard” in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following subsection of the Tutorial chapter:
  → Electrical metrology standards – Frequency and time standards

- Examine and reflect on the Example: GPS receiver data stream section of the Case Tutorial chapter,
  and answer the following questions:
  → What are some of the data available from an NMEA-0183 formatted message output by a GPS
    radio receiver?
  → Are there any data fields redundant to each other in the example data capture shown?

- Complete “Measuring time in Python” in the Quantitative Reasoning section of the Questions chapter.

- Download the datasheet for a precision oscillator module and identify the following information within
  the document:
  → Type of output signal waveform
  → Nominal frequency of the output signal
  → Stability of the output frequency
  → Startup time
  → Any special features?

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you
learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem
on your own prior to class as well. Expect the instructor to question your answers – even when correct – and
always challenge you to reason from first principles. Mastery of these principles only comes through practice,
and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

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

**Theory Session Expectations:**

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  - What is Instrumentation?
  - Terms and definitions
  - Control system examples
- Complete “Choosing proper controller action” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Diesel engine speed monitor” in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Theory session 56

Source text – Analog Instrumentation Circuits learning module


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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
Complete the following prior to the scheduled session with your instructor:

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

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

Theory Session Expectations:

Thoroughly read the assigned text(s) and write in your Theory Journal your own summary of what you learned as well as any questions of your own. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.
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”).

file wt 0296
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:

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

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

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

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
Problem #2

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

<table>
<thead>
<tr>
<th>Applied pressure (&quot; WC)</th>
<th>Output signal (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
The Rockwell/Allen-Bradley MicroLogix 1000 programmable logic controller (PLC) can handle up to four analog input signals: two with a 0-10 V maximum range and two with a 0-20 mA maximum signal range. This PLC’s analog input terminal block looks like this (the internal resistors are shown inside the PLC box):

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

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
Problem #4

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

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

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

Grading

[10%] (per correct answer)

Note: full credit given only for answers that are correct and logically supported by trusted principles.
Problem #5

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

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
Problem #6

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

![Diagram of the solar collector system]

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

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
Examine the following Python script designed to control a programmable DC power supply and a benchtop digital multimeter, used to test a DC amplifier circuit’s transfer function and output those test values in comma-separated variable format:

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

Grading

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

Note: full credit given only for answers that are correct and logically supported by trusted principles.
The written exam will consist of the following types of questions and their related principles:

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

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

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

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

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