IETTI-222 – Intermediate Electronics Theory (Semester 3 THEORY)

NAME: _____ Last update 7 October 2026

Session	Topic	Journal	P.S.	Comments
Session 01	Intro to the Career			
Session 02	C coding – basics			
Session 03	C coding and DC review			
Session 04	C coding – user input			
Session 05	C coding and AC review			
Session 06	C coding – if/loops			
Session 07	C coding and C/L review			
Session 08	C coding and filter review			
Session 09	MSP430G2553 MCU (I)			
Session 10	MSP430G2553 MCU (II)			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 13	Transistor switching review			
Session 14	Transistor biasing			
Session 15	Single-stage BJT amplifiers (I)			
Session 16	Thévenin's / Norton's review			
Session 17	Single-stage BJT amplifiers (II)			
Session 18	Multi-transistor amplifiers (I)			
Session 19	Multi-transistor amplifiers (II)			
Session 20	Amplifier performance			
Session 21	Oscillators			
Session 22	PCB layout			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 25	C coding – functions			
Session 26	Frequency-domain review			
Session 27	Transmission lines			
Session 28	Basic principles of radio			
Session 29	Radio antennas			
Session 30	Antenna feed systems			
Session 31	RF link budgets (I)			
Session 32	RF link budgets (II)			
Session 33	Intro to modulation			
Session 34	High-frequency amplifiers			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 37	Comparators			
Session 38	Feedback			
Session 39	Opamp basics			
Session 40	Opamps with controlled gain			
Session 41	Subtractors and summers			
Session 42	Opamp power boosting			
Session 43	Precision rectification			
Session 44	Opamp time-based functions			
Session 45	Opamp oscillators			
Session 46	Review of opamp concepts			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 49	AC induction motor starters (I)			
Session 50	AC induction motor starters (II)			
Session 51	VFDs (I)			
Session 52	VFDs (II)			
Session 53	Electrical power grids			
Session 54	Circuit breakers / disconnects			
Session 55	Principles of protective relays			
Session 56	Instrument transformers			
Session 57	Overcurrent relays			
Session 58	Differential current relays			
Session 59	ORAL PRESENTATIONS			
Session 60	EXAM			

Essential information about this course:

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

Values

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

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

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

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

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

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

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

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

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

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

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

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

file `eet_values`

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 reviews DC and AC circuit theory while introducing principles of C-language computer programming, then builds on that foundation to explore analog amplifier circuits (both discrete-transistor and operational amplifier), principles of RF and radio systems, operational amplifier circuits, AC motor controls, and protective relaying. 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 resistor networks, time-delay networks, AC reactive networks, transistor amplifiers, simple RF circuits, operational amplifier circuits, and AC power control circuits given schematic diagrams, component values, and other circuit parameters. (Addresses Program Learning Outcomes 4, 6)
- Compute component values necessary to achieve stated performance goals in resistor networks, transistor amplifier circuits, RF communication circuits, operational amplifier circuits, and AC power control circuits. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple filter networks, transistor amplifier circuits, operational amplifier circuits, and AC power control circuits to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to fundamental DC/AC circuit theory, analog electronics, RF systems, and AC power circuits as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in resistor networks, transistor amplifier circuits, radio transceiver systems, operational amplifier circuits, and AC power control circuits given schematic diagrams and reported symptoms. (Addresses Program Learning Outcomes 5, 6)
- Summarize physical laws and concepts related to the aforementioned circuit types, acquired from technical literature, and clearly present them in both written (journal) and oral formats. (Addresses Program Learning Outcomes 1, 6, 7)

Required Tools, Supplies, and Software

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

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

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

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

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

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

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

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

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

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

file `eet_tools`

Grading standards for Theory courses

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

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

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

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

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

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

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

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

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

file `eet_grading_t`

Instructor guidelines

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

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

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

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

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

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

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

Theory session 01

Source text – *Career Guide* learning module

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

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

- Read, reflect, and update your Theory Journal on the "Interviews and the Screening Process" chapter of the *Career Guide* document
- Research open positions on job search engines (e.g. `Indeed.com`) searching for job titles listed in the "What is Electronics" chapter, focusing on those jobs listing a two-year (Associate's) degree in electrical or electronics technology for education

Complete the following *during* the scheduled session:

- Discuss what you read in the *Career Guide*
  → Share your answers for selected "Sample Technical Questions"
  → Share your answers for selected "Sample Behavioral Questions"
- Discuss what you found in your job search:
  → What technical skills are common to these jobs?
  → What non-technical skills are common to these jobs?
- Discuss philosophy and design of the program:
  → Focus on building human capital: technical knowledge/skill *and* professional habits
  → Active learning: reading, writing, dialoguing, budgeting time and resources
  → Frequent feedback and clear deliverables built into every course
  → Any behavior that would get you fired from a job will result in a failing grade in any course here
- Discuss time commitment: *a minimum of 3 hours per week per enrolled credit is necessary for success! If you're taking a full load of courses, plan to be here all day every day!*
- [Optional] – sign FERPA release forms
- [Recommended] – *be available to give advice to the new students this semester!*

`Important resources:`

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

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Theory session 02

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

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

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

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

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

Theory Session Expectations:

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

file wt_0218

Theory session 03

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

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Formatted output using `printf`
  → Data types
  → Basic mathematical functions
  → Using the C math library
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Using C to analyze a series resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze a parallel resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze a series-parallel resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

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

Theory Session Expectations:

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

file wt_0219

Theory session 04

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

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

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

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Formatted input using `scanf`
- Complete "Using C to analyze a multi-source circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find mistakes in a millimeter conversion program" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting, run at least one simulation within the `sp` series-parallel simulation software challenging you to solve for all component voltages, currents, and power dissipations in different circuit configurations starting with just one resistor's voltage drop, current, or power.

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

Theory Session Expectations:

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

file wt_0220

Theory session 05

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

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

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

- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's problem-solving.
- Complete "Using C to analyze a series AC RLC circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze a parallel AC RLC circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using complex numbers in C to analyze a series-parallel AC RLC circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Case-sensitivity in variable names" in the Diagnostic Reasoning section of the Questions chapter.
- Identify specific modules in the Modular Electronics Learning Project collection with tutorials and practice problems to refresh your knowledge of the AC circuit concepts you find most challenging.

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

Theory Session Expectations:

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

file wt_0221

Theory session 06

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

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Conditionals
  → Loops
- Complete "Resonant frequency calculator program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Using C to plot a sine wave" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Geometric sequence counting 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.

If time permits during the theory session, watch a video demonstration of `Sonic Pi` which is an application allowing you to create music using coding (in the Ruby language). A good example is Dylan Beattie's presentation "The Art of Code" during the 27-31 January 2020 NDC Conference, available on YouTube. The section of this presentation where Beattie discusses `Sonic Pi` runs from 43:00 to 46:40.

Theory Session Expectations:

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

file wt_0222

Theory session 07

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

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

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

- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's problem-solving.
- Complete "RC time-constant calculator program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze an RC charging-discharging circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Writing an LR time-delay analysis program" in the Quantitative Reasoning section of the Questions chapter.
- Identify specific modules in the Modular Electronics Learning Project collection with tutorials and practice problems to refresh your knowledge of capacitor and inductor time-delay circuits.

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

Theory Session Expectations:

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

file wt_0223

Theory session 08

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

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

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

- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's problem-solving.
- Complete "Using C to analyze a series AC resistor-capacitor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Writing a cutoff frequency calculator program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Writing a low-pass filter simulation program" in the Quantitative Reasoning section of the Questions chapter.

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

Theory Session Expectations:

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

file wt_0224

Theory session 09

Source text – *Texas Instruments MSP430 Microcontrollers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_mcu_430.pdf`

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → MSP430G2553 pin functions
  → Elementary output and input
- Examine the C example: alternating LED blink section of the Case Tutorial chapter and answer the following questions:
  → What is the proper DC power supply voltage for the MSP430 microcontroller?
  → Which pins are connected for this example circuit, and what are their functions?
  → How are the correct I/O pins referenced in the C code, to blink the LEDs on and off?
  → Which I/O pins are instructed to function as outputs, and which (if any) as inputs, in this program?
  → This program makes use of a *function* which is a feature of the C programming language we haven't studied yet. See if you can figure out how this works!
- Complete "Integer conversion table" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Poor interface design" in the Diagnostic Reasoning section of the Questions chapter.

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

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

Theory Session Expectations:

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

file wt_0225

Theory session 10

Source text – *Texas Instruments MSP430 Microcontrollers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_mcu_430.pdf`

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → CCS assembly-language programming
  → CCS C-language programming
  → Energia programming
- Complete "Terminal assignments and limits" in the Conceptual Reasoning section of the Questions chapter.
- Compare and contrast three different Case Tutorial sections on programs that add two numbers together (one written in Assembly, one written in C, and one written in Sketch). Then, answer the following questions:
  → Identify the value of the calculated sum, in each example
  → Which two out of these three programming languages appears most similar to each other?
  → How are *comments* shown in each of the three languages?
- Compare and contrast two different Case Tutorial sections on programs that control LED states using pushbutton inputs (one written in Assembly and one written in C). Then, answer the following questions:
  → In each language, how does the program "test" the status of the pushbutton switch?
  → In each language, how does the program set or clear the LED's status?
  → What advantages and disadvantages do you see to each programming language as used in the MSP430 microcontroller?
  → How are pre-defined constants such as `BIT0` useful in programming the MSP430 microcontroller?

Theory Session Expectations:

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

file wt_0226

Theory session 11

Oral Presentations

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

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

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

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

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

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_0227

Problem #1

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

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

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

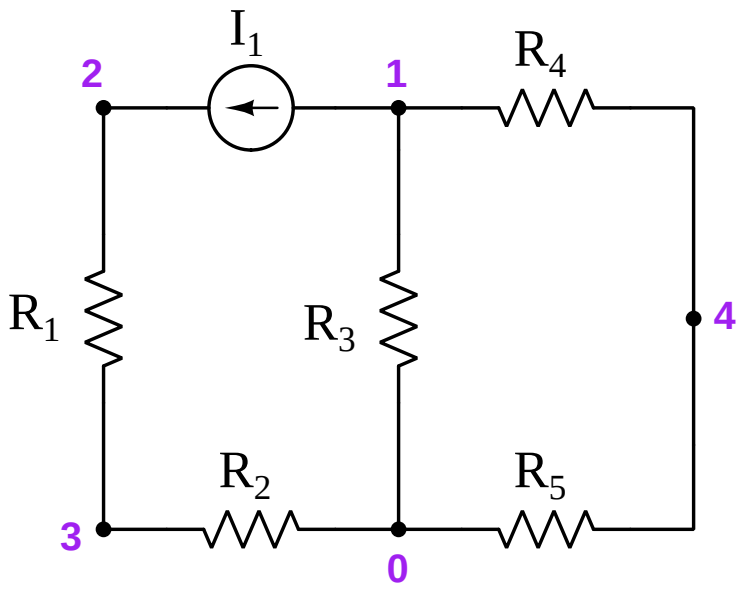
`Grading`

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

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

Problem #2

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

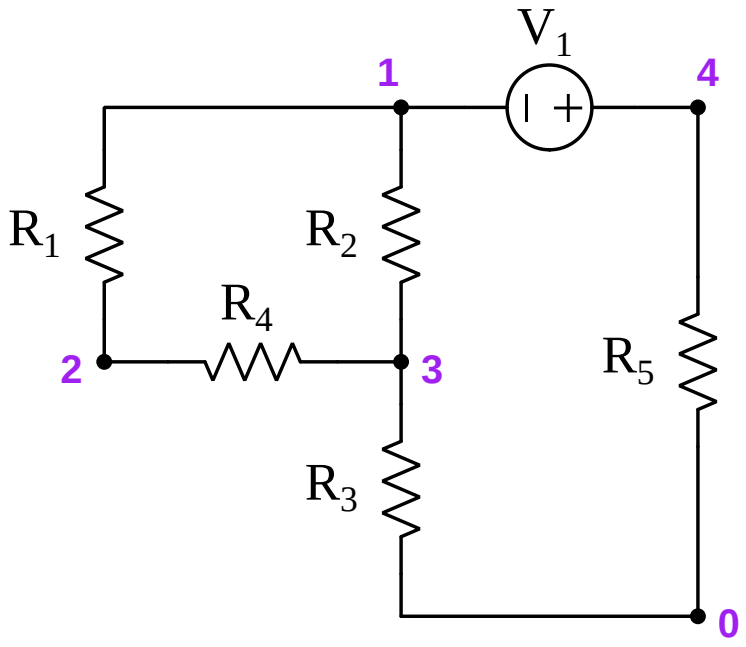
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_3 (I_{R3})
- ◯ [20%] Current magnitude and direction through node 4 (I_4)
- ◯ [20%] All current magnitudes and directions at node 1
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ◯ [20%] Voltage magnitude and polarity across resistor R_2 (V_{R2})

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

Problem #3

(Component values randomly chosen by instructor):



Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during technical interviews for electronics technician jobs.

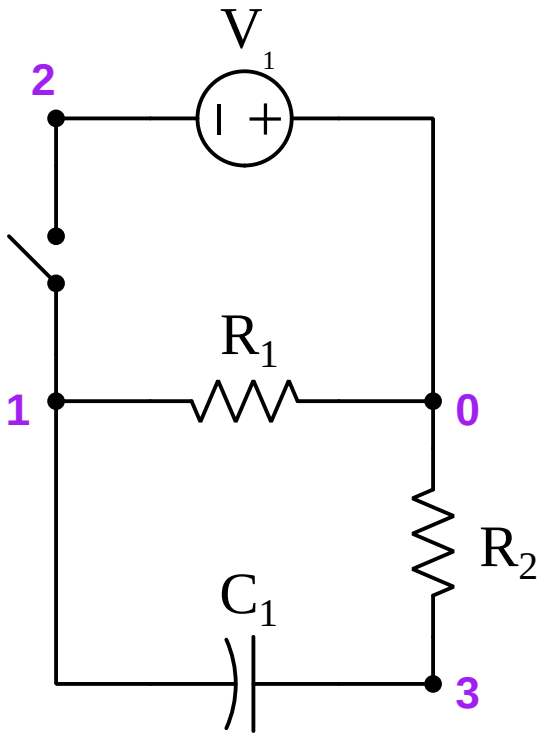
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] All current magnitudes and directions entering and exiting node 3
- ◯ [20%] Voltage magnitude and polarity between nodes 3 and 4 (V_{3-4})
- ◯ [20%] Voltage magnitude and polarity across resistor R_3 (V_{R3})

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

Problem #4

Assume the switch has been in the (*open/closed*) state long enough for the capacitor's voltage to stabilize, and is suddenly toggled to the opposite state at time $t = 0$. All component values will be randomly chosen by instructor, as well as the point in time ($t =$ _____) at which all values will be calculated:



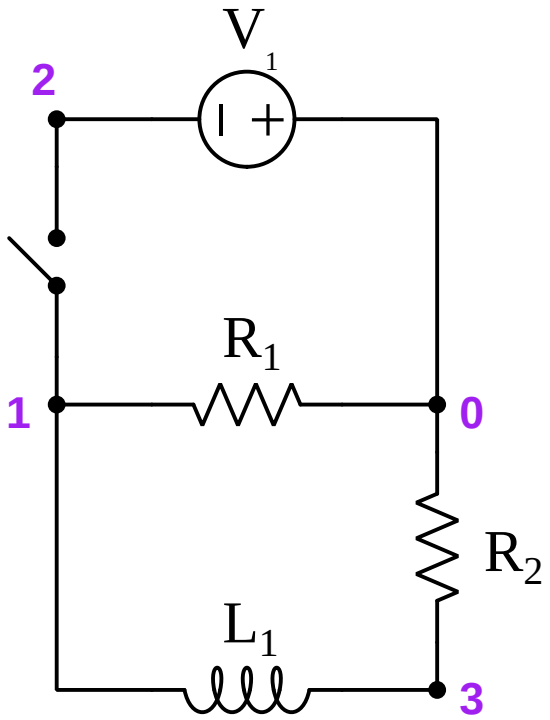
`Grading`

- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] Current magnitude and direction through capacitor C_1 (I_{C1})
- ◯ [20%] Voltage magnitude and polarity across capacitor C_1 (V_{C1})
- ◯ [20%] Voltage magnitude and polarity across resistor R_1 (V_{R1})
- ◯ [20%] Energy stored in capacitor at time ($t =$ _____ seconds)

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

Problem #5

Assume the switch has been in the (*open/closed*) state long enough for the inductor's current to stabilize, and is suddenly toggled to the opposite state at time $t = 0$. All component values will be randomly chosen by instructor, as well as the point in time ($t =$ _____) at which all values will be calculated:



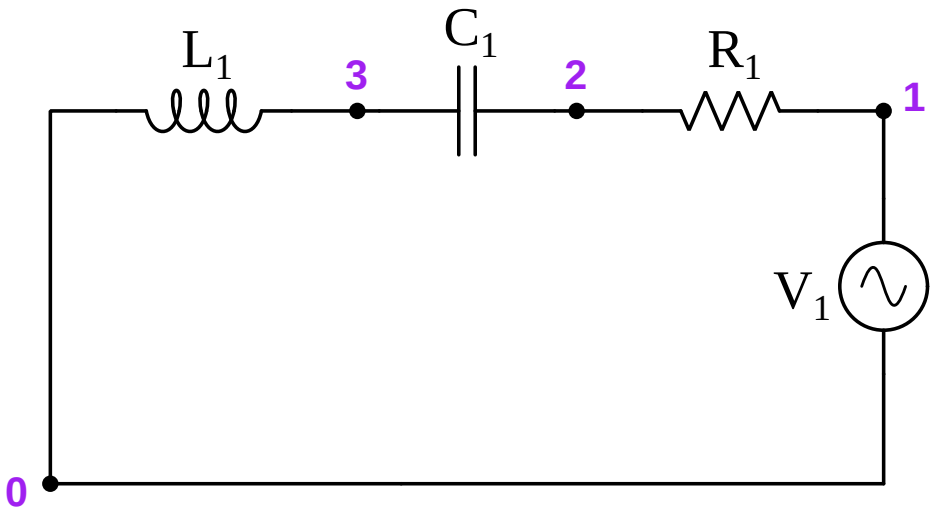
`Grading`

- ◯ [20%] Current magnitude and direction through node 2 (I_2)
- ◯ [20%] Current magnitude and direction through inductor L_1 (I_{L1})
- ◯ [20%] Voltage magnitude and polarity across inductor L_1 (V_{L1})
- ◯ [20%] Voltage magnitude and polarity across resistor R_1 (V_{R1})
- ◯ [20%] Energy stored in inductor at time ($t =$ _____ milliseconds)

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

Problem #6

(Component values randomly chosen by instructor):



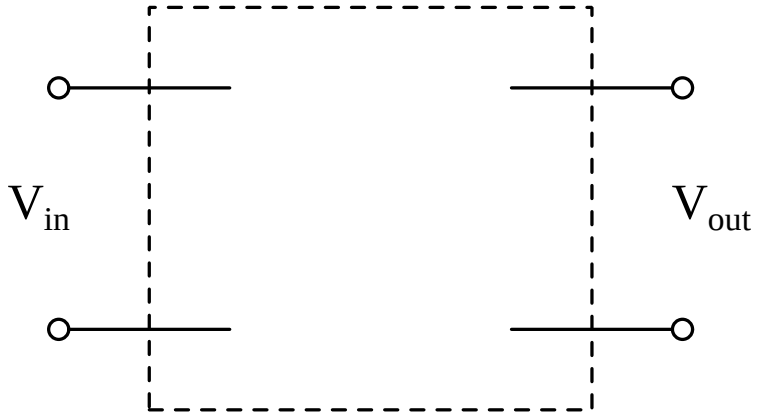
`Grading`

- ◯ [20%] Voltage magnitude and phase angle across resistor R_1 (V_{R1})
- ◯ [20%] Voltage magnitude and phase angle across capacitor C_1 (V_{C1})
- ◯ [20%] Voltage magnitude and phase angle across inductor L_1 (V_{L1})
- ◯ [20%] Total (source) current magnitude and phase angle (I_{total})
- ◯ [20%] Power factor

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

Problem #7

Design a passive filter network meeting performance characteristics randomly chosen by instructor:



- Type of filter = (*low-pass/high-pass*)
- f_{cutoff} = _____ Hertz
- Using (*inductor/capacitor*)
- Minimum input impedance = _____ Ohms @ cut-off

`Grading`

◯ [20%] Proper pass characteristic (either low- or high-pass)
◯ [20%] Correct f_{cutoff} with component values chosen
◯ [20%] Predict effect(s) of resistor failing open
◯ [20%] Predict effect(s) of reactive component (L or C) failing open
◯ [20%] Calculate Z_{in} at f_{cutoff}

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

Problem #8

Write a simple C program to perform one of the following operations, chosen at random by the instructor, and demonstrate its successful operation on your own computer:

- Input two integer values from the user and display the product (multiplication) of those two numbers
- Input two integer values from the user and display the sum (addition) of those two numbers
- Input two integer values from the user and display the difference (subtraction) of those two numbers
- Input one integer value from the user and produce an indication of whether or not it is an even value
- Input one integer value from the user and produce an indication of whether or not it is a positive value
- Input one integer value from the user and produce an indication of whether or not it is evenly divisible by _____
- Input one integer value from the user and then display a count from that value upward until the count reaches a value of _____
- Input one integer value from the user and then display a count from that value downward until the count reaches a value of _____

`Grading`

◯ [20%] Program compiles without error(s)
◯ [20%] Correctly explain the purpose of all statements in your program
◯ [20%] Identify any alternative coding solutions to the same problem
◯ [20%] Correctly explain the purpose of a *conditional* instruction, whether used in your program or not
◯ [20%] Correctly explain the purpose of a *looping* instruction, whether used in your program or not

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

Theory session 12

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

- (Question #1) Calculate voltage, current, resistance, and/or power in a series DC resistor circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks

- (Question #2) Calculate voltage, current, resistance, and/or power in a parallel DC resistor circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of parallel networks

- (Question #3) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel DC 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 #4) 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 #5) 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 #6) Design and sketch a passive filter circuit with a specified cutoff frequency and characteristic.
  Filter circuit behavior, capacitive reactance, inductive reactance, resonance

- (Question #7) Calculate voltage, current, and/or impedance in a series or parallel AC network.
  Capacitive reactance, inductive reactance, impedance, complex-number arithmetic, properties of series networks, properties of parallel networks, Ohm's Law, Kirchhoff's Laws

- (Question #8) 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) Determine logic states within a combinational logic circuit.
  Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts

file wt_0215

Theory session 13

Source text – *Transistor switching circuits* learning module

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

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

- Read the Tutorial chapter as necessary to refresh your memory on this subject.
- Compare the flip-book animations showing BJT operation and MOSFET operation in the Animations chapter, and answer the following questions:
  - → What causes a BJT to become conductive between emitter and collector terminals?
  - → What causes a MOSFET to become conductive between source and drain terminals?
  - → Which of these transistor types requires more controlling voltage (V_{BE} or V_{GS}) to turn on?
  - → Which of these transistor types drops less voltage (V_{CE} or V_{DS}) when saturated on?
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Transistor summary" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Proper BJT types" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "BJT switching circuit simulation program" in the Quantitative Reasoning section of the Questions chapter.

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

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

Theory Session Expectations:

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

file wt_0229

Theory session 14

Source text – *Transistor Biasing* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Another BJT with slow-changing DC input" in the Conceptual Reasoning section of the Questions chapter.
- Complete "BJT amplifier biasing strategies" in the Conceptual Reasoning section of the Questions chapter.
- Complete "DC signal sweep simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0039

Theory session 15

Source text – *Single-Stage BJT Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Amplifier fundamentals
  → BJT amplifier configurations
  → Common-collector amplifier
  → Common-emitter amplifier
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Altering common-emitter resistor values" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Common-emitter calculations" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – if time permits, write a computer program in a text-based language simulating the "Common-emitter calculations" circuit example.

Theory Session Expectations:

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

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0040

Theory session 16

Source text – *Thévenin's and Norton's Theorems* learning module

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

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

- Read the Tutorial chapter as necessary to refresh your memory on this subject.
- Examine and reflect on the following sections of the Case Tutorial chapter, identifying which foundational concepts (e.g. Ohm's Law, Kirchhoff's Laws, etc.) were applied to calculate the values shown:
  → Example: Thévenizing a multi-source network
  → Example: Nortonizing a multi-source network
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Thévenizing a loaded voltage divider" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Fault current of a battery bank" in the Diagnostic Reasoning section of the Questions chapter.
- **Coding challenge** – if time permits, write a computer program in a text-based language simulating any of the questions answered today or any of the example circuits shown in the Tutorial.

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

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

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- Animation of Thévenin's Theorem section of the Animations chapter.

  file wt_0230

Theory session 17

Source text – *Single-Stage BJT Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Common-base amplifier
  → Amplifier gain comparisons
  → Input and output impedances
  → Amplifier design example: swamped common-emitter
- Complete "Achieving a specified voltage gain" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Common-emitter quiescent simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulty audio amplifier design" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0041

Theory session 18

Source text – *Multi-Transistor Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Paired transistors
  → Cascaded stages
  → Push-pull amplifiers
- Complete "Audio amplifier evaluation" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Approximating voltage gain" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Amplifier simulation program" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Animation of class-B crossover distortion section of the Animations chapter.

  file wt_0074

Theory session 19

Source text – *Multi-Transistor Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Differential pairs
  → Current mirrors
  → Active loading
- Complete "Model 324 differential amplifier qualitative analysis" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Audio amplifier quiescent values" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Current mirror calculations" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – if time permits, write a computer program in a text-based language simulating a current source's behavior either with a swept supply voltage or a changing load resistance.

Theory Session Expectations:

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

`Additional resources:`

- Animation of class-B crossover distortion section of the Animations chapter.

  file wt_0231

Theory session 20

Source text – *Amplifier Performance* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Impulse testing" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Gain ratios into decibels" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Decibels into gain ratios" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to convert gain ratios into decibels or vice-versa.
- Complete "Audio amplifier design improvement" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0075

Theory session 21

Source text – *Oscillators* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Neon lamp relaxation oscillator" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Colpitts oscillator frequency" in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to calculate the resonant frequency of an oscillator circuit based on its L and C component values.
- Complete "Effects of faults in a strobe light circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- William Hewlett's Oscillator section of the Historical References chapter.
- LC Resonance section of the Derivations and Technical References chapter.

file wt_0056

Theory session 22

Source text – *Printed Circuit Boards* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial:
  → Introduction to PCBs
  → PCB construction
  → Layout tools
  → Basic layout elements
  → PCB layout best practices
  → Preserving signal integrity
- Read, reflect, and update your Theory Journal on the Trace ampacity ratings section of the Derivations and Technical References chapter.
- Read, reflect, and update your Theory Journal on the Trace voltage ratings section of the Derivations and Technical References chapter.
- Complete "Applying foundational concepts to a series-parallel circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Current measurement on a PCB" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Transistor amplifier circuit on PCB" in the Diagnostic Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to take a user-input distance value in "thous" and convert to both inches and millimeters.

Theory Session Expectations:

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

file wt_0278

Theory session 23

Oral Presentations

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

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

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

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

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

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

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

Note: all schematic diagrams for these problems are annotated with node numbers. These will be helpful when describing locations in the circuit for your audience, but they also serve as a cue on how to *practice*. Simply write a SPICE netlist using these node numbers, inserting component values of your choice, and then use SPICE to verify the results you calculate. Using SPICE, you may make as many versions of these circuits for practice as you would like! For example, the circuit of problem #1 may be converted into the following SPICE netlist (assuming all resistors are 1 kΩ in size, the voltage source is 12 Volts, and the switch is closed):

```
* Netlist
v1 0 3 dc 12
r1 2 4 1000
rswitch 3 4 1e-3
rload 1 3 1000
q1 1 2 0 bjt
.model bjt pnp bf=100
.op
.end
```

file wt_0232

Problem #1

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

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

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

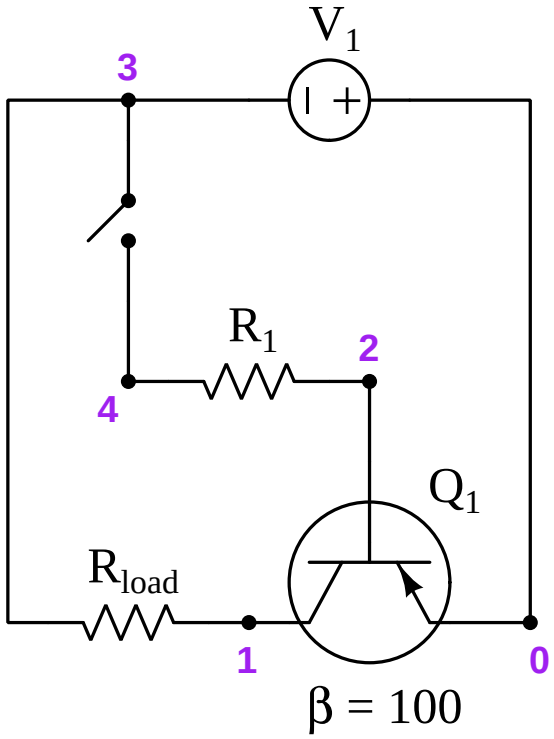
`Grading`

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

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

Problem #2

V_1 and R_{load} component values randomly chosen by instructor. Assume R_1 size chosen to ensure transistor saturation when "on":



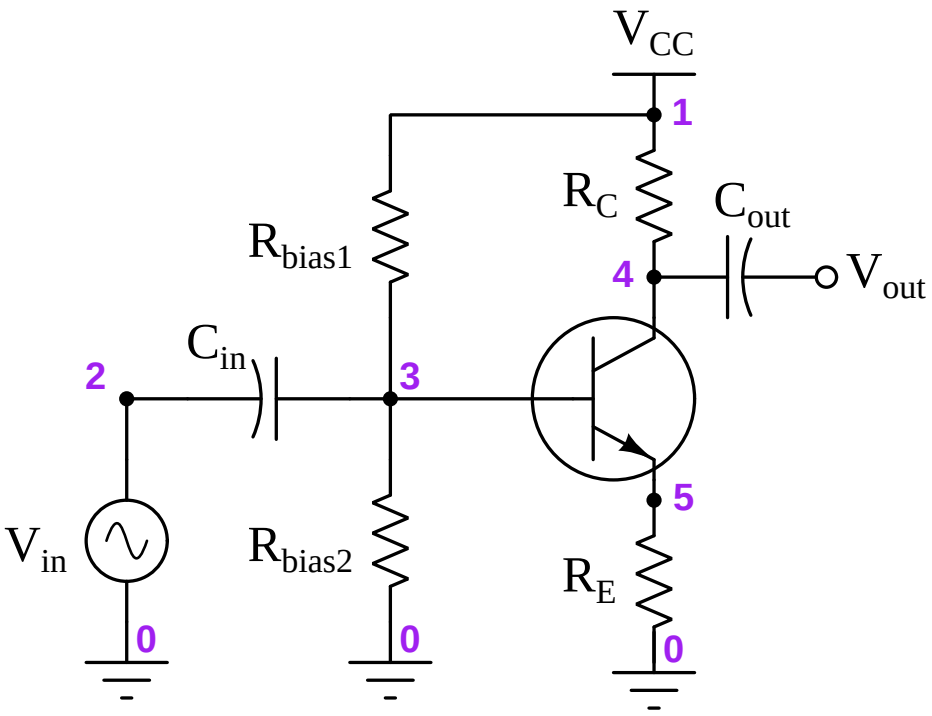
Grading

- ◯ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch closed
- ◯ [20%] Voltage magnitude and polarity between collector and emitter (V_{CE}) when switch open
- ◯ [20%] Power dissipated by transistor Q_1 when switch closed
- ◯ [20%] Resistance value for resistor R_1 that would ensure saturation

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

Problem #3

(Component values randomly chosen by instructor):



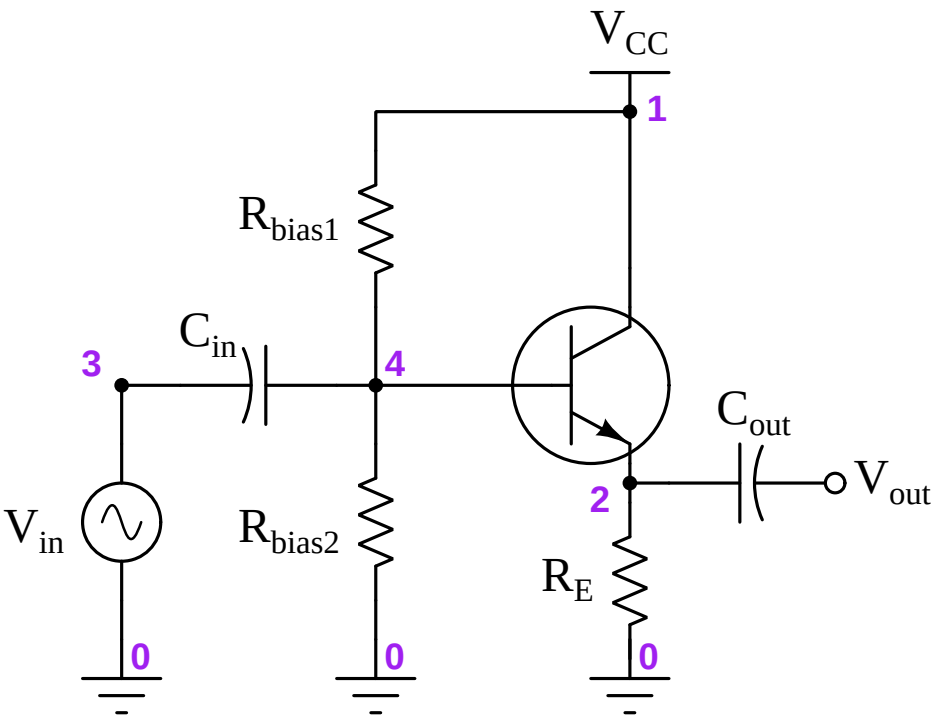
`Grading`

- ◯ [20%] Voltage gain (A_V) as a ratio and as a decibel value
- ◯ [20%] Input impedance (Z_{in})
- ◯ [20%] Output impedance (Z_{out})
- ◯ [20%] Assuming your choice of bias resistor values, specify a DC quiescent voltage V_B suitable for Class-A operation
- ◯ [20%] Largest AC value of V_{in} without clipping, assuming Class-A operation

Note: full credit given only for answers that are correct and logically supported by trusted principles. Note that approximations are permissible, since exact computations can be overwhelmingly complex in discrete-transistor amplifier networks.

Problem #4

(Component values randomly chosen by instructor):



`Grading`

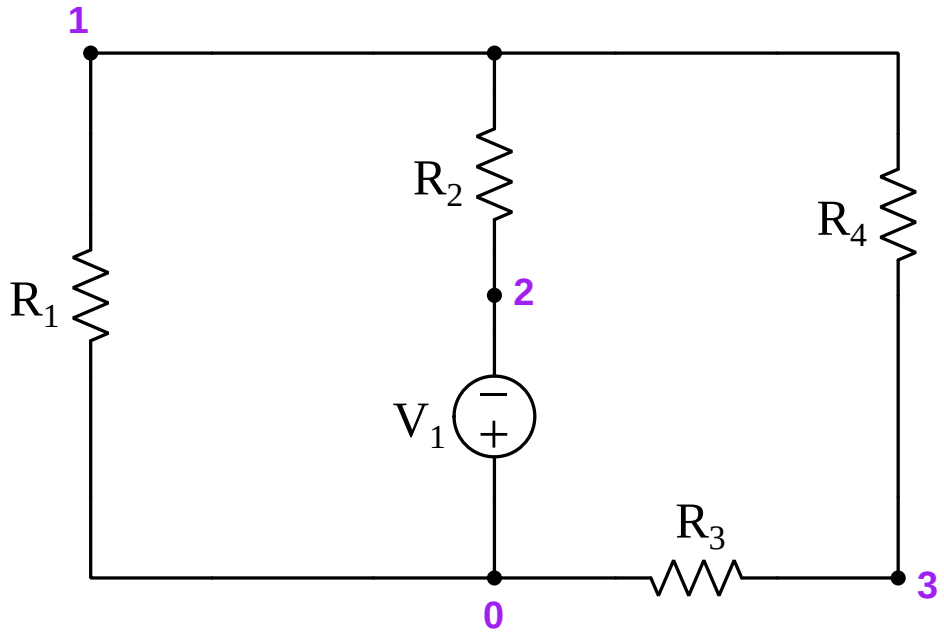
- ◯ [20%] Voltage gain (A_V) as a ratio and as a decibel value
- ◯ [20%] Input impedance (Z_{in})
- ◯ [20%] Output impedance (Z_{out})
- ◯ [20%] Assuming your choice of bias resistor values, specify a DC quiescent voltage V_B suitable for Class-A operation
- ◯ [20%] Largest AC value of V_{in} without clipping, assuming Class-A operation

Note: full credit given only for answers that are correct and logically supported by trusted principles. Note that approximations are permissible, since exact computations can be overwhelmingly complex in discrete-transistor amplifier networks.

Problem #5

(Component values randomly chosen by instructor):

Thévenize this circuit, assuming resistor _____ is the load:



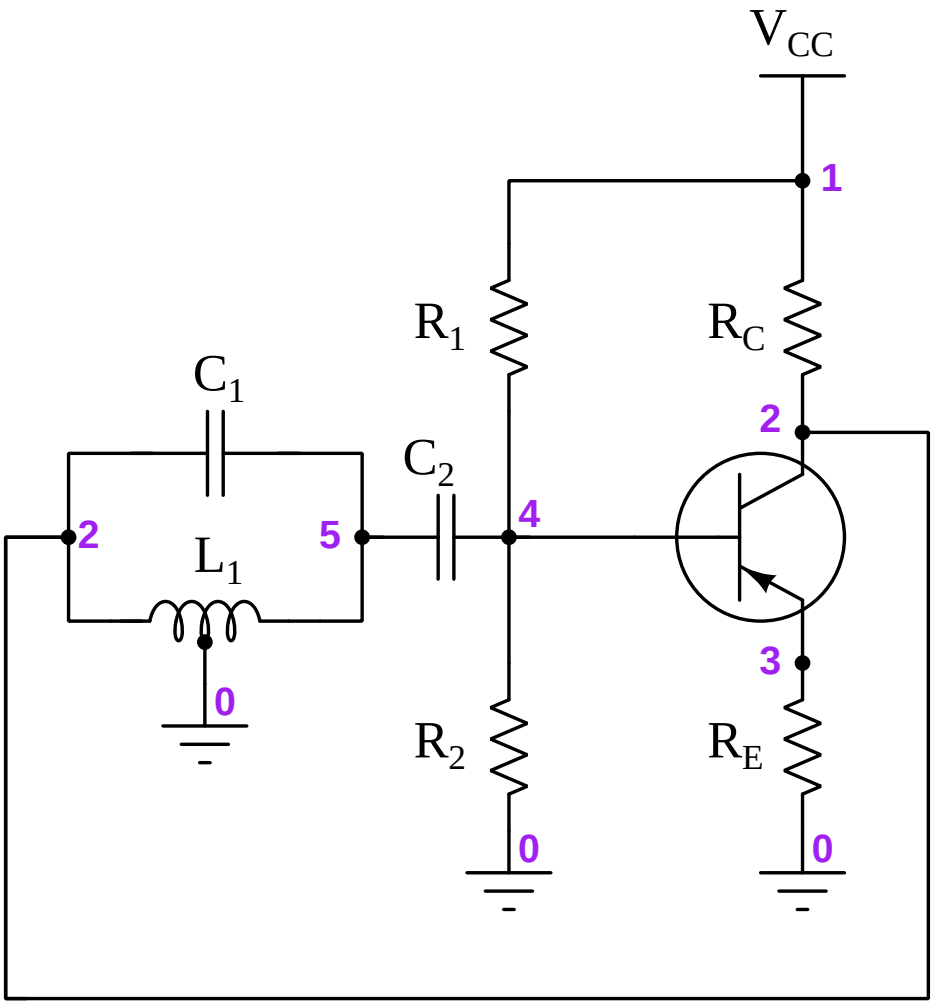
`Grading`

- ◯ [20%] Thévenin equivalent voltage (V_{Th})
- ◯ [20%] Thévenin equivalent resistance (R_{Th})
- ◯ [20%] Load current magnitude (I_{load})
- ◯ [20%] Load resistance value necessary for maximum load power (P_{load})
- ◯ [20%] Sketch diagram of Thévenin equivalent circuit powering the load

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

Problem #6

(Component values randomly chosen by instructor):



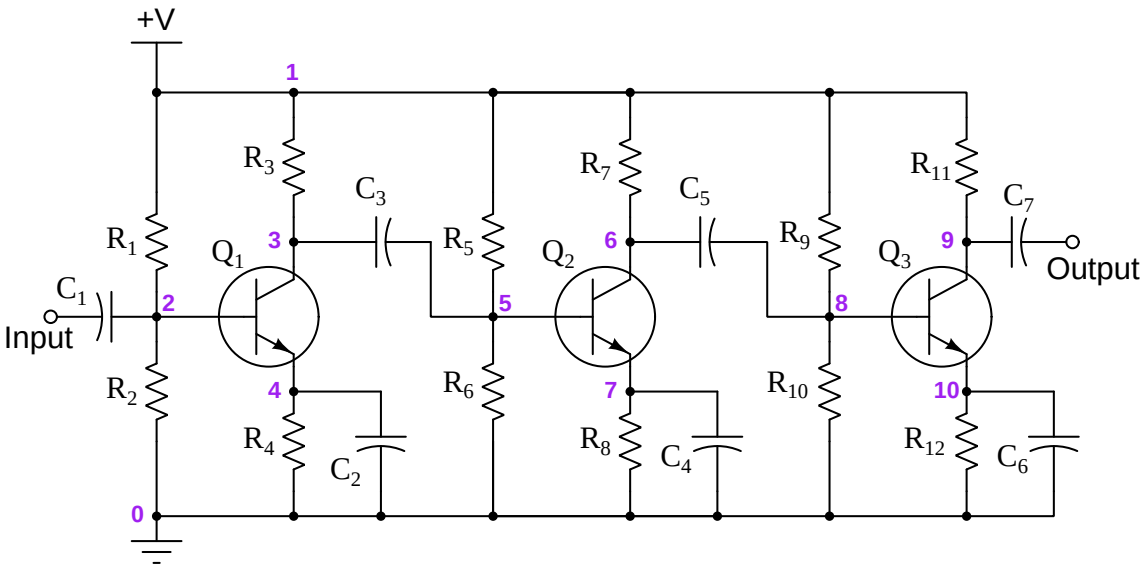
`Grading`

- ◯ [20%] Voltage gain (A_V) as a ratio and as a decibel value
- ◯ [20%] Output frequency (f_{out})
- ◯ [20%] Reactance of C_2 at operating frequency
- ◯ [20%] Assuming your choice of bias resistor values, specify a DC quiescent voltage V_B suitable for Class-A operation
- ◯ [20%] Largest AC value of V_{in} without clipping, assuming Class-A operation

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

Problem #7

Predict the effects of resistor _____ failing (*open/shorted*), assuming the circuit is amplifying an AC signal in class-A operation when the fault occurs:



`Grading`

- ◯ [20%] AC signal voltage (increases/decreases/remains the same) between nodes __ and __ ($V_{?-?}$)
- ◯ [20%] AC signal voltage (increases/decreases/remains the same) between nodes __ and __ ($V_{?-?}$)
- ◯ [20%] DC quiescent voltage (increases/decreases/remains the same) between nodes __ and __ ($V_{?-?}$)
- ◯ [20%] DC quiescent voltage (increases/decreases/ remains the same) across resistor $R_?$ ($V_{R?}$)
- ◯ [20%] DC quiescent voltage (increases/decreases/ remains the same) across capacitor $C_?$ ($V_{C?}$)

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

Theory session 24

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

- (Question #1) Design and sketch a circuit using either a BJT or an FET to switch DC power to a load.
  BJT behavior, FET behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks

- (Question #2) Calculate voltages and currents in a series-parallel AC circuit.
  Capacitive reactance, inductive reactance, impedance, complex-number arithmetic, properties of series networks, properties of parallel networks, Ohm's Law, Kirchhoff's Laws

- (Question #3) 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 #4) Calculate the approximate gain for a multi-stage BJT amplifier circuit based on component values or signal measurements, expressed as both a ratio and a decibel figure.
  Ohm's Law, BJT behavior, BJT amplifier behavior, gain calculations, decibels

- (Question #5) Calculate voltages, currents, and/or power dissipations in a BJT or FET switching circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior

- (Question #6) Select appropriate components to set the frequency of an oscillator.
  Ohm's Law, properties of series and parallel networks, resonance, tank circuits, Wein bridge networks

- (Question #7) Determine possible faults in a discrete-transistor amplifier circuit.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, effects of opens vs. shorts, amplifier behavior

- (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) Design and sketch an unloaded voltage divider network given required voltage and/or current values.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks

file wt_0216

Theory session 25

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

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

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

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Functions
- Complete "Decibel calculator program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sine calculator program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find mistake in a function-calling program" in the Diagnostic 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.

If time permits during the theory session, explore the Rockstar programming language, a parody language created by Dylan Beattie allowing one to write functioning code that can also be 1980's style rock song lyrics. A good video exploration of Rockstar is found in Dylan Beattie's presentation "The Art of Code" during the 27-31 January 2020 NDC Conference, available on YouTube. The section of Beattie's presentation on Rockstar runs from 46:40 to 55:50.

Theory Session Expectations:

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

file wt_0228

Theory session 26

Source text – *Frequency-Domain Analysis* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Full Tutorial chapter:
  → Composition of light
  → Fourier's Theorem
  → Time vs. frequency in circuits
  → Time-frequency relationships
  → Applications for frequency-domain analysis
- Read, reflect, and update your Theory Journal on the Fourier series for common waveforms section of the Derivations and Technical References chapter.
  → Explain what some of the variables represent in these series (ω, t)
  → Explain what some of the numerical coefficients mean in these series ($\frac{1}{n}$, $\frac{1}{n^2}$)
- Complete "LR circuit energized by a square-wave source" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Fourier series in code" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Discerning even/odd harmonics from the time domain" in the Diagnostic Reasoning section of the Questions chapter.

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

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

Theory Session Expectations:

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

file wt_0113

Theory session 27

Source text – *Transmission Lines* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "TDR cable fault testing" in the Conceptual Reasoning section of the Questions chapter.
- Complete "TDR calculator program in C" 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.

Theory Session Expectations:

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

`Additional resources:`

- Animation of an open transmission line section of the Animations chapter.
- Animation of a shorted transmission line section of the Animations chapter.
- Animation of a terminated transmission line section of the Animations chapter.
- Animation of a standing wave with full reflection section of the Animations chapter.

  file wt_0037

Theory session 28

Source text – *Basic Principles of Radio* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Quarter-wave antenna" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Frequency-wavelength calculator program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "RF emissions from a computer PCB" in the Diagnostic Reasoning section of the Questions chapter.
- Locate the FCC's Office of Engineering and Technology (OET) Bulletin number 63 on low-power non-licensed transmitters (found in the `Regulatory_Government/` directory of your EETREF document collection), read the relevant section(s), and answer the following questions:
  - → In what ways are experimental (i.e. home-made) devices restricted by the FCC?
  - → What are the penalties for non-compliance with an experimental transmitter?
  - → Suppose you are building a prototype transmitter with intent to eventually market it – how do the requirements differ from those of a purely experimental or hobbyist transmitter?
  - → How may we estimate the power output of a transmitter (in Watts) based on measured electric field strength (in Volts/meter) and distance from transmitting antenna (in meters)?

Theory Session Expectations:

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

file wt_0160

Theory session 29

Source text – *Radio Antennas* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Basic antenna types
  → Antenna size
  → Dipole voltage and current distributions
  → Antenna polarization and directionality
  → Antenna reciprocity
  → Antenna characteristics (and all subsections showing different antenna types)
- Complete "Parabolic dish feed" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Antenna dimensions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Incorrect decibel calculation program" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0161

Theory session 30

Source text – *Antenna Feed Systems* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Antenna feed systems
  → Antennas as sources and loads
  → Feedlines
  → Excessive standing wave ratio
  → Antenna impedance matching
  → Transceiver impedance matching
  → Surge suppression and grounding
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Ultimate Transmatch" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Transformer impedance ratios" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Matching section calculator program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0174

Theory session 31

Source text – *RF Link Budgets* learning module

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

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

- Read, reflect, and update your Theory Journal on the Decibels section of the Derivations and Technical References chapter.
  → *A helpful tip when learning any math-heavy concept from text is to perform all the mathematical examples yourself, checking to see that you get the same results!*
- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Effective radiated power
- Complete "Cable loss and frequency" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power ratio and dB conversions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Power and loss calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Waveguide power loss" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0162

Theory session 32

Source text – *RF Link Budgets* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Link budget fundamentals
  → Link budget graph
  → Fresnel zones
- Complete "Link budget graph" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Using C to calculate receiver power" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Minimum transmitter power" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Possible faults in radio SCADA system" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform a full link budget calculation, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Make a formula note page listing every new formula you encounter, the necessary units of measurement, and a description of what it means
- Work through each representative example problem 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!*
- Carefully organize all your numerical results in link budget calculations, using either a table and/or a link budget graph!

Theory Session Expectations:

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

file wt_0173

Theory session 33

Source text – *Introduction to Modulation* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Introduction to modulation
  → Amplitude modulation
  → Frequency modulation
  → Phase modulation
  → Pulse modulation
  → Frequency-shifting
- Complete "Carrier-less radio" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Oscillographs comparing sinusoids" in the Quantitative Reasoning section of the Questions chapter.
- Examine and reflect on the Example: downconverting AM receiver section of the Case Tutorial chapter, and answer the following questions:
  → Explain how signal mixing is used to shift the frequency of the received signal at each stage
  → Explain how filtering is used after each mixer to select the desired signal(s) and reject all others

Theory Session Expectations:

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

file wt_0165

Theory session 34

Source text – *High-Frequency Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Locate the Texas Instruments CC1190 datasheet for their 850-950 MHz "RF front end" IC (document SWRS089A revised February 2010, found in the `Datasheets/RF` directory of your EETREF document collection) and answer the following questions:
  - → Examine the block diagram for this device and identify the function of each block within it, as well as the functions of all externally-connected components
  - → Identify the functions of the three digital control pins (`PA_EN`, `LNA_EN`, and `HGM`) on this IC
  - → Identify the maximum RF power output of this device's power amplifier (PA) as well as its efficiency in percent
  - → Identify whether this "front end" IC is designed for *balanced* or *unbalanced* RF signals
  - → In one mode this IC's receiver gain may be set to −6 dB. Explain what a negative decibel gain figure means in practical terms, and also propose a scenario where this might be useful.
- Complete "Solid-state PA component functions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Tank circuit calculator program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in a low-power CW transmitter" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0176

Theory session 35

Oral Presentations

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

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

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

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

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

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

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

file wt_0234

Problem #1

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

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

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

`Grading`

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

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

Problem #2

Calculate parameters associated with the link budget for a radio transmitter/receiver network. The following parameters will be randomly chosen by the instructor:

- Distance between transmitting and receiving antennae (in either miles or kilometers)
- Frequency of RF signal (in Hertz)
- Sensitivity of receiver (in dBm)
- RF power output of transmitter (either in Watts or dBm/dBW/etc.)

Assume no losses between the transmitter and its antenna, or between the receiver and its antenna.

`Grading`

◯ [20%] RF signal loss over space between antennae, assuming perfect conditions (in dB)
◯ [20%] Wavelength of RF signal (λ) in meters and also in feet
◯ [20%] Minimum antenna height for first Fresnel zone to clear ground (assuming perfect conditions)
◯ [20%] DC power necesssary to run the transmitter, assuming ____% RF power amplifier efficiency
◯ [20%] Methods to improve reception without modifying transmitter or receiver electronics

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

Problem #3

Calculate parameters associated with a coaxial cable used to connect the output of a radio transmitter to its antenna, assuming perfect impedance matching throughout the system. The following parameters will be randomly chosen by the instructor:

- Cable velocity factor
- Cable length
- Cable loss (dB per foot or meter)

The instructor will also choose random power values to fill in the "blank" spaces below. The unit of measurement for each power will also be random (e.g. Watts, milliWatts, dBm, dBW, etc.).

`Grading`

◯ [20%] Power received by antenna at ____ transmitter output power
◯ [20%] Power dissipated by cable at ____ transmitter output power
◯ [20%] Necessary transmitter output power to deliver ____ of power to antenna
◯ [20%] Transmitter output power when cable dissipates ____ of heat
◯ [20%] Signal propagation time from one end of cable to the other

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

Problem #4

Sketch three different types of radio antennas (all specified by instructor) and comment on their characteristics:

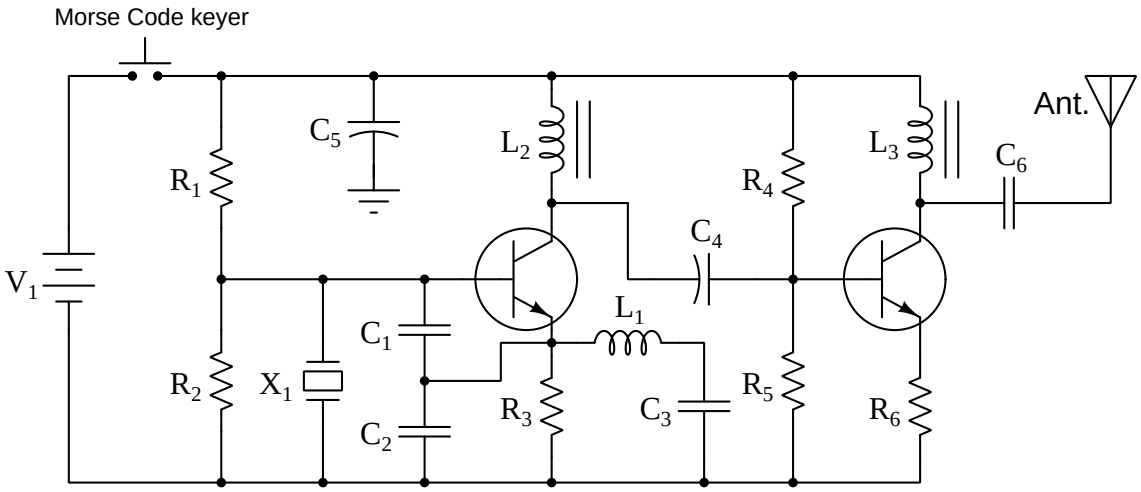
`Grading`

- ◯ [10%] Identify radiation pattern of first antenna
- ◯ [10%] Identify whether the feed line for the first antenna will be balanced or unbalanced
- ◯ [10%] Identify radiation pattern of second antenna
- ◯ [10%] Identify whether the feed line for the second antenna will be balanced or unbalanced
- ◯ [10%] Identify radiation pattern of third antenna
- ◯ [10%] Identify whether the feed line for the third antenna will be balanced or unbalanced
- ◯ [10%] Identify which antenna is the most *directional*
- ◯ [10%] Identify which antenna exhibits the least *gain*
- ◯ [20%] EIRP of a ____ Watt transmitter connected to a ____ dBi gain antenna

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

Problem #5

Analyze this radio circuit design:



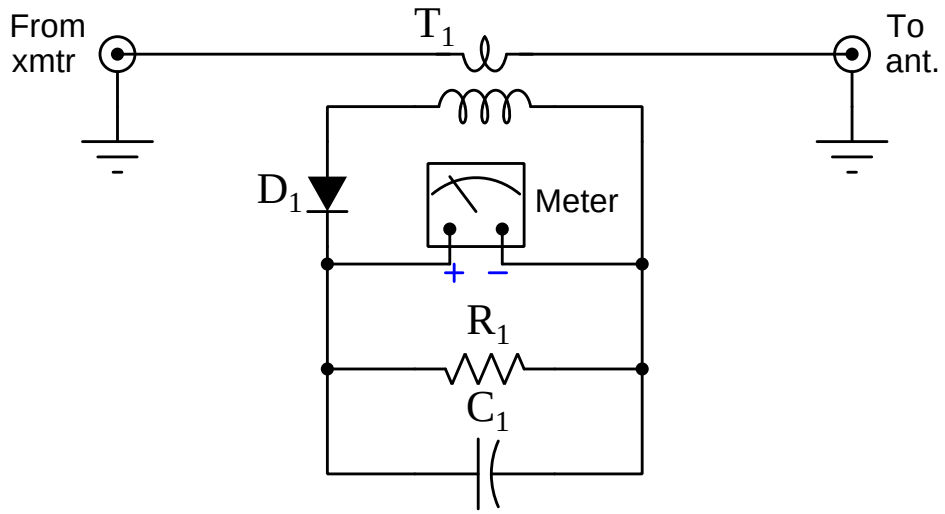
`Grading`

- ◯ [20%] Identify what would have to be altered to (*increase/decrease*) its carrier frequency
- ◯ [20%] Identify the effect(s) of ____ failing (*open/shorted*)
- ◯ [20%] Identify ways to increase the physical range of this radio circuit
- ◯ [20%] Explain how you could test this circuit for proper operation with its antenna disconnected
- ◯ [20%] Explain how you could send a message to someone using this transmitter

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

Problem #6

Analyze the following instrument, designed to provide an approximate measurement of RF power from a transmitter to its antenna:



Grading

- ◯ [20%] How is the *DC* meter able to operate from the *AC* power on the transmission line?
- ◯ [20%] Explain how you could use this instrument to indicate when an antenna "tuner" had been properly adjusted
- ◯ [20%] Identify one cause for sub-optimal power transfer in a real antenna system
- ◯ [20%] Identify another cause for sub-optimal power transfer in a real antenna system
- ◯ [20%] Identify the effect(s) of ____ failing (*open/shorted*)

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

Problem #7

Sketch a schematic diagram showing a radio transmitter with 50 Ohm output impedance (unbalanced) connected to a 50 Ohm coaxial cable transmission line, impedance-matched to a monopole antenna having an impedance of ____ Ohms. Assume an operating frequency of ____ Hertz.

`Grading`

- ◯ [20%] Sketch a matching network based on a *transformer*
- ◯ [20%] Propose primary and secondary turns values for this transformer
- ◯ [20%] Sketch a matching network based on a *matching section*
- ◯ [20%] Propose impedance and length for the matching section
- ◯ [20%] Explain in detail why a matching network is beneficial to this application

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

Theory session 36

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

- (Question #1) Determine the appropriate dimensions for a radio antenna given signal frequency, or vice-versa.
  Wavelength calculations, speed of light, antenna types and configurations (e.g. monopole, dipole, Yagi, loop), conversions between metric and imperial units of length

- (Question #2) Compute power gains/losses in radio communication systems using decibels.
  Decibels, power dissipation in RF cables, antenna gain, RF link budgets

- (Question #3) 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 #4) Identify the effect of faults in a radio transmitter or receiver circuit.
  Modulation and demodulation schemes, mixer circuits, effects of opens and shorts, oscilloscope display interpretation, spectrum analyzer display interpretation

- (Question #5) 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

- (Question #6) Identify the purposes of individual components within an RF amplifier circuit, given a schematic diagram.
  Transistor amplifier configurations (e.g. common-base, etc.), RF chokes, bypass capacitors, coupling, amplifier biasing

- (Question #7) Determine necessary circuit parameters and/or configurations to properly match feedlines with other components (e.g. transceiver, antenna) in an RF system.
  Transmission lines, standing wave ratio (SWR), transformer impedance ratios, quarter-wave matching sections, purpose of LC matching networks, Maximum Power Transfer Theorem, Thévenin's/Norton's Theorems, velocity factor, speed of light, antenna size in relation to frequency

- (Question #8 – REVIEW) Calculate voltages, currents, and/or powers in a transformer circuit
  Transformer behavior, Ohm's Law, Joule's Law

- (Question #9 – REVIEW) Apply right-triangle trigonometry to the solution of practical distance problems.
  Law of sines, Pythagorean Theorem, sine function, cosine function, tangent function

file wt_0217

Theory session 37

Source text – *Comparators* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Determining output polarities" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Hysteretic comparator with rail-to-rail output" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Swept-voltage comparator simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in thermostat circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- The "Example: comparator response to various inputs" section of the Case Tutorial chapter gives insightful examples of a comparator responding to different input conditions.
- Differential pair amplifiers section of the Derivations and Technical References chapter.
- Comparator generating PWM waveform section of the Animations chapter.

  file wt_0050

Theory session 38

Source text – *Feedback* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Miscalibrated speedometer" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Mathematical functions in feedback path" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Loss of servo feedback" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0042

Theory session 39

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Electronic amplifiers
  → Differential inputs and outputs
  → Integrated circuit amplifiers
  → Amplifier split power supplies
  → Negative feedback
  → Regulation
  → Servos and control systems
  → Attenuated and offset feedback
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Fooling a voltage regulator" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Load current path" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltage follower simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Internal faults in a model TL082" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0043

Theory session 40

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Inverting and noninverting amplification
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Read, reflect, and update your Theory Journal on the Split DC power supplies section of the Derivations and Technical References chapter.
- Complete "Calculating output voltages and gains" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Necessary resistor values for specified voltage gains" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Calculating input and output voltages" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of faults on a simple amplifier circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0044

Theory session 41

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Differential amplification
  → Summation
- Complete "Vocal eliminator circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Subtractor calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Summer circuit calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Summer circuit simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0114

Theory session 42

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Precision current circuits
  → Boosted output
- Read, reflect, and update your Theory Journal on the Operational amplifier imperfections section of the Derivations and Technical References chapter.
- Complete "Unusual current-regulating circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Current regulator simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Troubleshooting a microphone amplifier" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0236

Theory session 43

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Precision rectification
- Complete "Opamp power rectifier?" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Precision rectifier simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Incorrect full-wave rectifier analysis" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0241

Theory session 44

Source text – *Operational Amplifiers* learning module

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

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

- Examine and reflect on the Example: measuring signal rates of change section of the Case Tutorial chapter, and answer the following questions:
  - → Explain how a $\frac{dV}{dt}$ value of +3.7 Volts per second differs fundamentally from a V value of +3.7 Volts
  - → Explain how to estimate $\frac{dV}{dt}$ values from a captured oscillograph
- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Integrators and differentiators
  → Analog computing
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Integrator calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Capacitor voltage simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0240

Theory session 45

Source text – *Operational Amplifiers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Oscillator circuits
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Three-phase oscillator simulation program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems. In particular, the section showing the design of a triangle/square/PWM oscillator is particularly relevant to this theory session's topic.
- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

  file wt_0242

Theory session 46

Source text – *Analog Engineer's Circuit Cookbook: Amplifiers*, Second edition

`EETREF/Tutorials/TI_AnalogEngineers_CircuitCookbook_Amplifiers_slyy137a.pdf`

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

- Read the following circuit examples and answer the associated questions:
  → Adjustable reference voltage circuit – determine all circuit voltages and currents at $\alpha = 0\%$, $\alpha = 50\%$, and $\alpha = 100\%$
  → High-side current-sensing circuit design – determine V_o at a current of 0.25 Amperes
  → Single-ended input to differential output circuit – determine V_{o-} and V_{o+} at an input signal voltage of 1.5 Volts
  → Relaxation oscillator circuit – reduce the R_2/R_3 voltage divider reference network to an equivalent Thévenin source, and then explain how this produces a sawtooth waveform centered around 2.5 Volts
- **Coding challenge** – write a simple computer program in a text-based language simulating the function of any of these circuits.

Theory Session Expectations:

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

file wt_0239

Theory session 47

Oral Presentations

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

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

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

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

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

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

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

file wt_0235

Problem #1

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

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

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

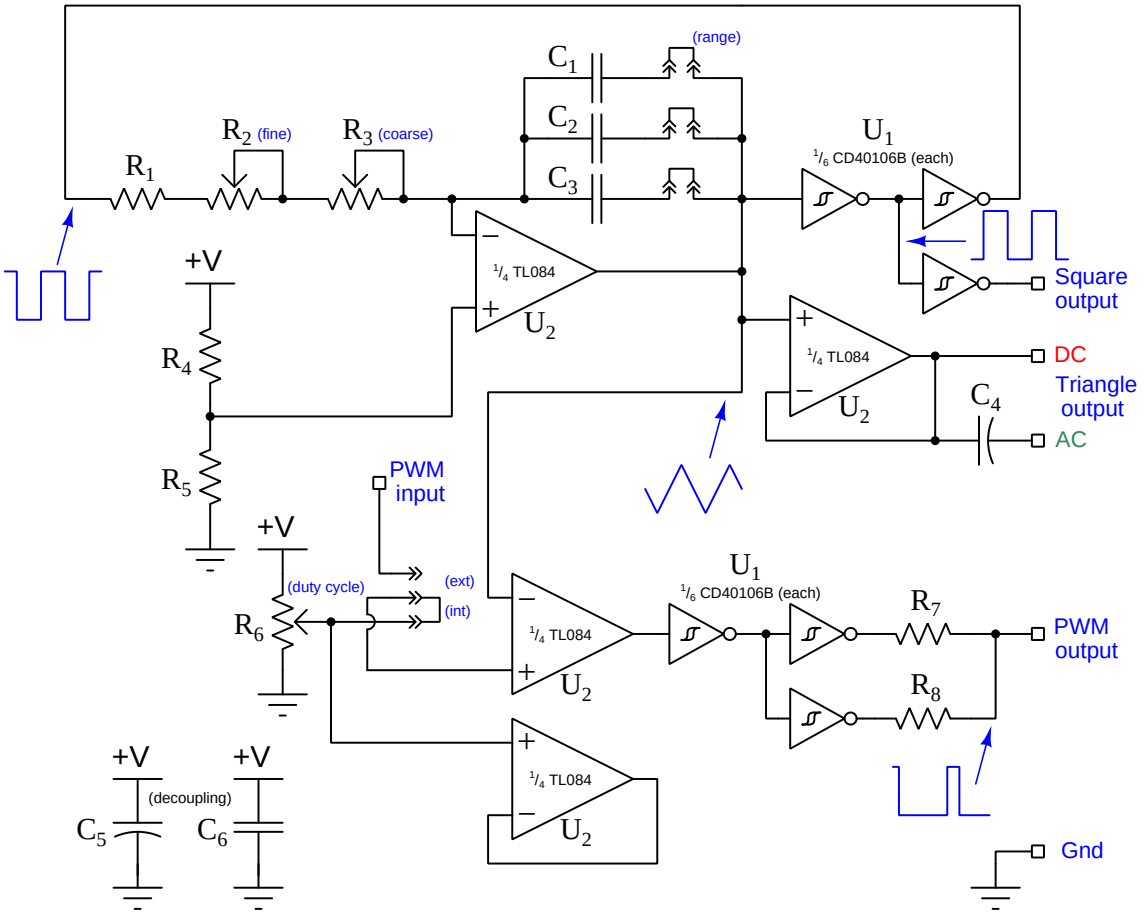
`Grading`

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

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

Problem #2

Evaluate this signal generator circuit:



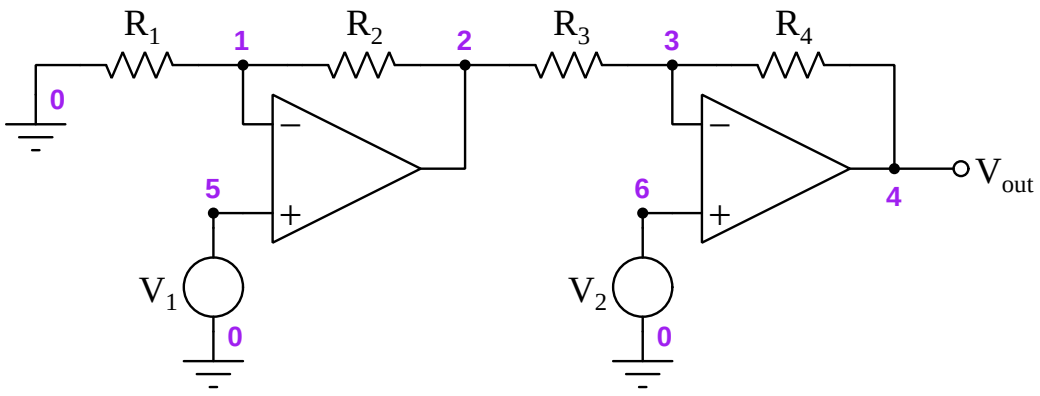
`Grading`

- ◯ [20%] Identify the function provided by each of the operational amplifiers
- ◯ [20%] Identify what portion of the circuit generates the oscillations
- ◯ [20%] Explain how one type of wave-shape gets converted into another type of wave-shape
- ◯ [20%] Explain how frequency is controlled in this oscillator circuit
- ◯ [20%] Explain how PWM duty cycle is controlled in this oscillator circuit

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

Problem #3

(Component values randomly chosen by instructor):



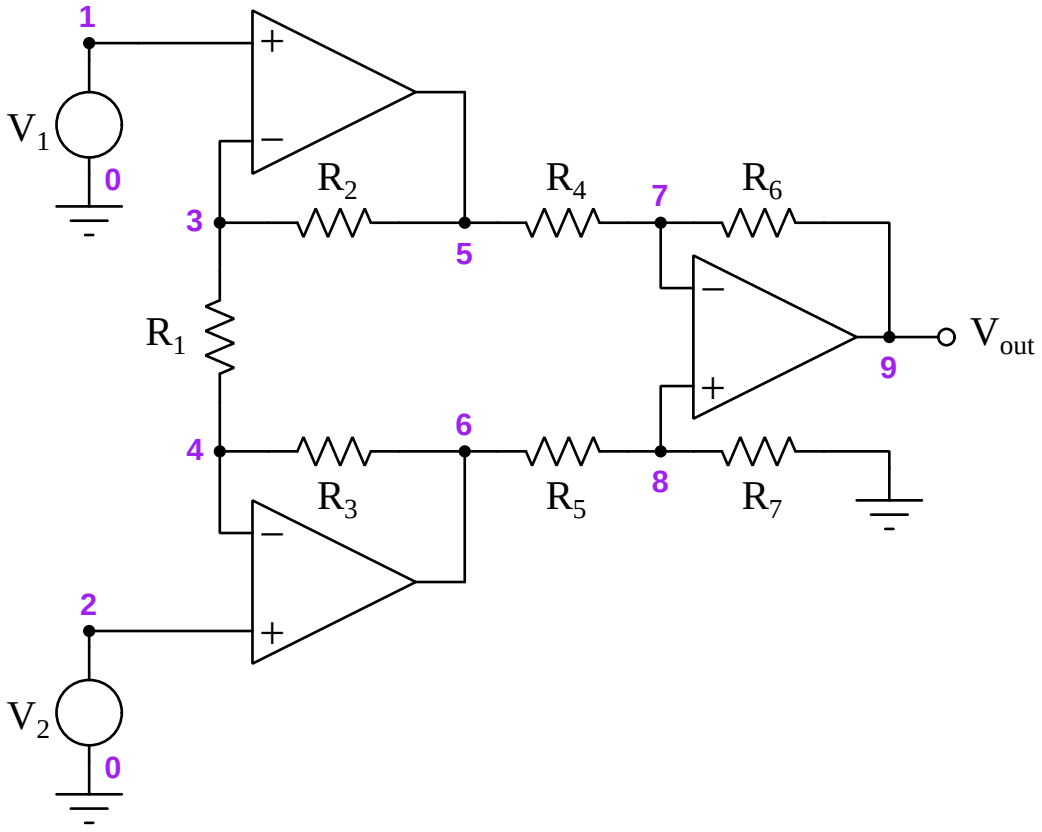
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ◯ [20%] Current magnitude and direction through node 6 (I_6)
- ◯ [20%] All current magnitudes and directions entering and exiting node 2
- ◯ [20%] Voltage magnitude and polarity between nodes 3 and 1 (V_{3-1})
- ◯ [20%] Voltage magnitude and polarity of V_{out}

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

Problem #4

(Instrumentation amplifier circuit – component values randomly chosen by instructor):



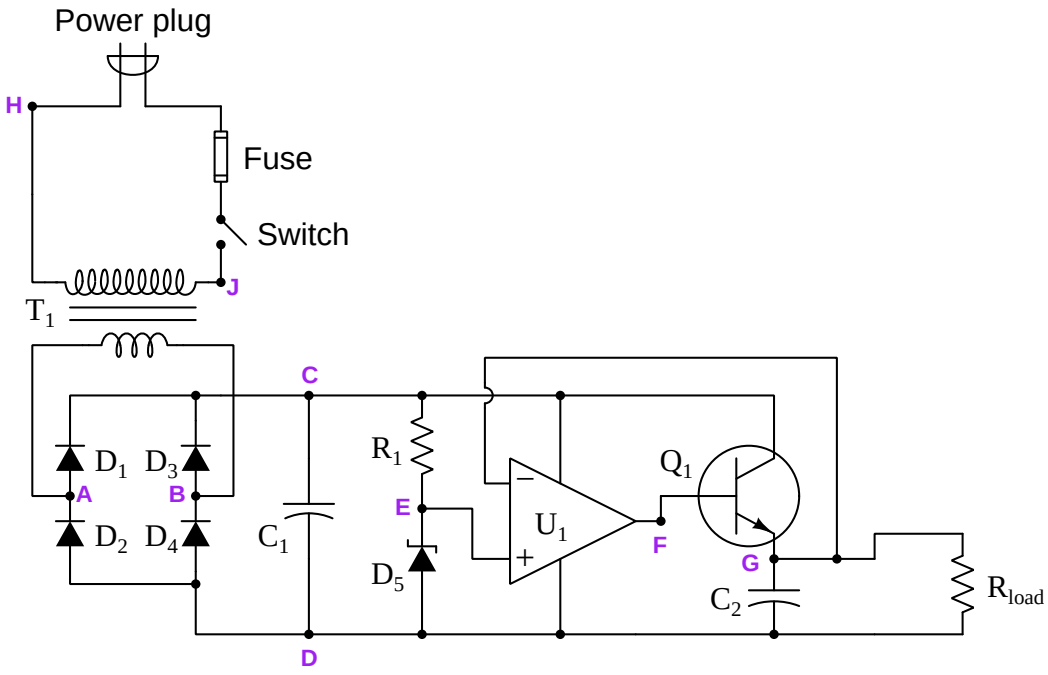
`Grading`

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

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

Problem #5

(Component values randomly chosen by instructor):



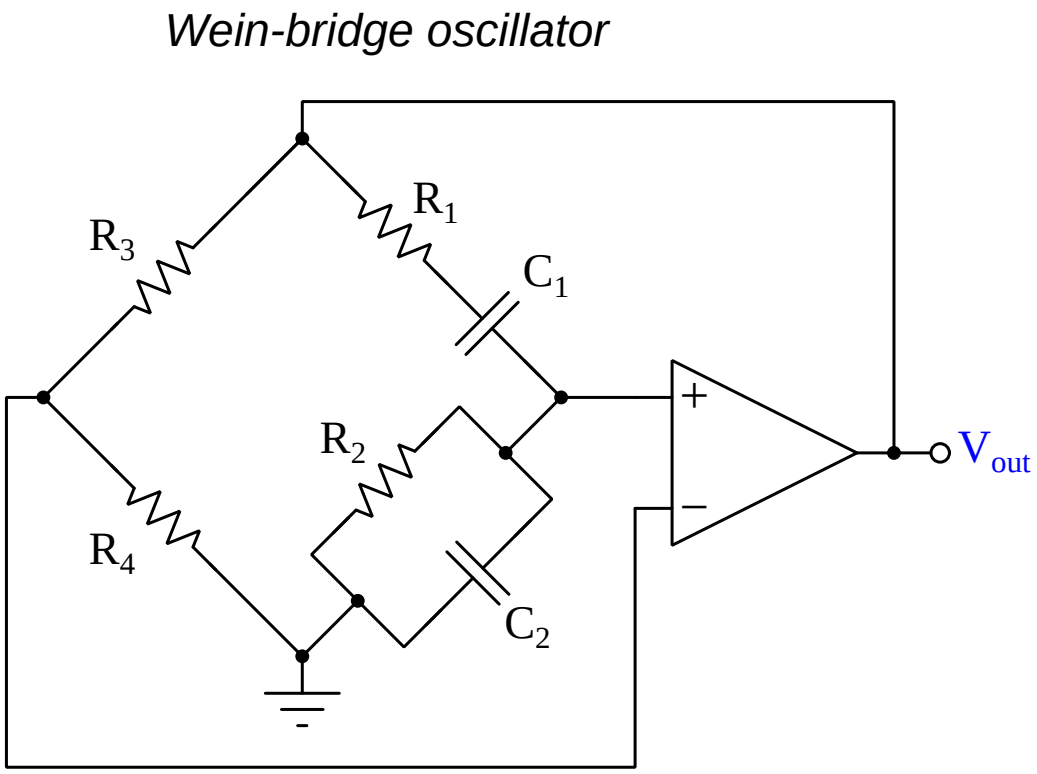
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and direction through load ($I_{R_{load}}$)
- ◯ [20%] Voltage magnitude and polarity between nodes F and G (V_{FG})
- ◯ [20%] Power dissipation of voltage-reference diode (P_{D_5})
- ◯ [20%] Energy stored in capacitor at its peak voltage (E_C)

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

Problem #6

(Frequency randomly chosen by instructor):



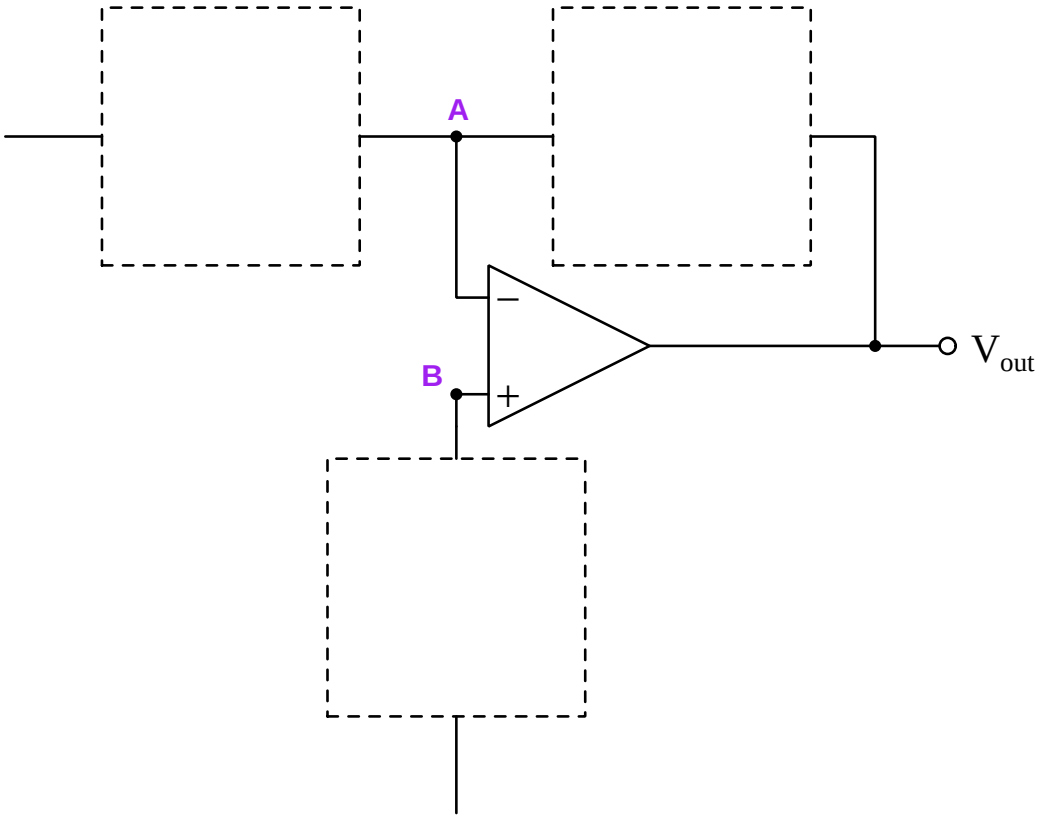
`Grading`

- ◯ [20%] Appropriate values for resistors R_1 and R_2, between 1 kΩ and 100 kΩ each
- ◯ [20%] Appropriate values for resistors R_3 and R_4, between 1 kΩ and 100 kΩ each
- ◯ [20%] Appropriate values for capacitors C_1 and C_2, between 0.001 μF and 1 μF each
- ◯ [20%] Effect on output signal if ____ fails (*open* or *shorted*)
- ◯ [20%] Effect on output signal if ____ fails (*open* or *shorted*)

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

Problem #7

Analyze this opamp circuit with random components inserted into it (component values randomly chosen by instructor):



`Grading`

- ◯ [20%] V_{out} when V_{in} = ____
- ◯ [20%] Opamp output terminal current when V_{out} = ____
- ◯ [20%] V_A when V_{in} = ____
- ◯ [20%] V_B when V_{in} = ____
- ◯ [20%] Consequence of ____ failing (*open* or *shorted*)

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

Theory session 48

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

- (Question #1) Determine input parameters (e.g. voltage, current, resistance) necessary to drive a comparator-based circuit into a given output state.
  Comparator behavior, Ohm's Law, Kirchhoff's Voltage Law, voltage dividers, Wheatstone bridge networks, shunt resistors for current measurement, AND/OR/NAND/NOR/XOR/NOT logic gate behavior

- (Question #2) 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 #3) Calculate voltages and/or currents in a conventional summer or subtractor operational amplifier circuit.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, negative feedback, opamp summer circuits, opamp differential amplifier circuits

- (Question #4) Calculate voltage and current values within an arbitrary operational amplifier circuit given component values and some given voltage and/or current values.
  Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, BJT amplifier behavior, negative feedback, opamp behavior, comparator behavior

- (Question #5) Calculate voltages and/or currents in an operational amplifier circuit conditioning a signal from a sensor or sensor network.
  Wheatstone bridge networks, voltage dividers, Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, voltage and current for a capacitor, negative feedback, opamp behavior, comparator behavior, integrator and differentiator behavior, shunt resistors

- (Question #6) Determine possible faults in a discrete-transistor or operational amplifier circuit.
  Ohm's Law, Kirchhoff's Laws, Properties of series and parallel networks, effects of opens vs. shorts, amplifier behavior, negative feedback, opamp behavior

- (Question #7 – REVIEW) Identify a passive filter circuit characteristic from its schematic diagram, and predict the effects of a component fault on that characteristic.
  Properties of series networks, properties of parallel networks, effects of opens vs. shorts, filter circuit behavior, capacitive reactance, inductive reactance

- (Question #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) Qualitatively predict voltage, current, and power changes in a series or parallel resistor circuit resulting from one component change.
  Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, properties of voltage sources, properties of current sources, limiting-cases analysis

file wt_0233

Theory session 49

Source text – *AC Induction Motor Starters* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Motor contactors
  → Motor overload protection
  → Latching motor starters
  → Digital motor controls
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Start/Jog control" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Microcontroller program for a simple motor starter" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Motor current calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted lift station pump control" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0195

Theory session 50

Source text – *AC Induction Motor Starters* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Automatic motor starting
  → Inrush current
  → Inrush-limited starting
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Sketching connections for a three-phase starter" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Wye motor fed by Delta source" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Motor current simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a relay-controlled motor (Circuit_008) using `tshoot` software, and show the final results.
  → Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series/parallel networks, Kirchhoff's Laws, etc.)

Theory Session Expectations:

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

file wt_0198

Theory session 51

Source text – *Variable-Frequency AC Motor and Servo Drives* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Basic VFD function
  → AC motor braking
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Currents within a VFD circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Grinding machine braking" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Three-phase simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Locate technical literature for a VFD with dynamic braking capability and identify the following information within the document(s):
  → Wiring diagram showing input AC power, connections to the motor, and where the braking resistor would connect
  → Ratings for motor drive power (voltage, current, and/or power in Watts)
  → Ratings for dynamic braking power (voltage, current, and/or power in Watts)
- If time permits, experiment with DC injection braking on a small AC induction motor to show just how powerfully effective this simple braking strategy is!

Theory Session Expectations:

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

file wt_0202

Theory session 52

Source text – *Variable-Frequency AC Motor and Servo Drives* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Important VFD parameters
  → Line reactors
- Complete "VFD/pump configuration" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Line reactor harmonic impedance" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Predicting effects of VFD component faults" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0203

Theory session 53

Source text – *Electrical Power Grids* learning module

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

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

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Faults in a power system" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Pole-mounted transformers" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Multi-source grid simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted and unfaulted phasor diagrams" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0204

Theory session 54

Source text – *Circuit Breakers and Disconnects* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Full Tutorial chapter:
  → Low-voltage circuit breakers
  → Medium-voltage circuit breakers
  → High-voltage circuit breakers
- Complete "Low-pressure lockout" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Trip time from oscillograph" in the Quantitative Reasoning section of the Questions chapter.
- Locate technical literature from a manufacturer of high-voltage circuit breakers (e.g. Siemens) and identify the following information within those documents:
  → Voltage and current ratings for at least one live-tank circuit breaker model
  → Voltage and current ratings for at least one dead-tank circuit breaker model
  → Type(s) of stored-energy mechanism(s) for tripping/closing

Theory Session Expectations:

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

file wt_0208

Theory session 55

Source text – *Principles of Protective Relaying* learning module

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

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

- Read, reflect, and update your Theory Journal on the Full Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Identifying protection zones" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Identifying which relays will pick up" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Median-select microcontroller program" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0108

Theory session 56

Source text – *Instrument Transformers* learning module

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

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

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Potential transformers
  → Current transformers
  → Instrument transformer safety
  → Instrument transformer test switches
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Multi-ratio CT wiring" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Transformer-isolated voltage calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Damaged data acquisition system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0209

Theory session 57

Source text – *Overcurrent Protection Relays* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_50_51_relay.pdf`

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Motor protection" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Three-phase 50/51 protection circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Trip time simulation program" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted 50/51 system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0210

Theory session 58

Source text – *Differential Generator, Line, and Bus Protection Relays* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_87GLB_relay.pdf`

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "87 line protection" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Faulted generator" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted 87 system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

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

file wt_0211

Theory session 59

Oral Presentations

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

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

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

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

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

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

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

Problem #1

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

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

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

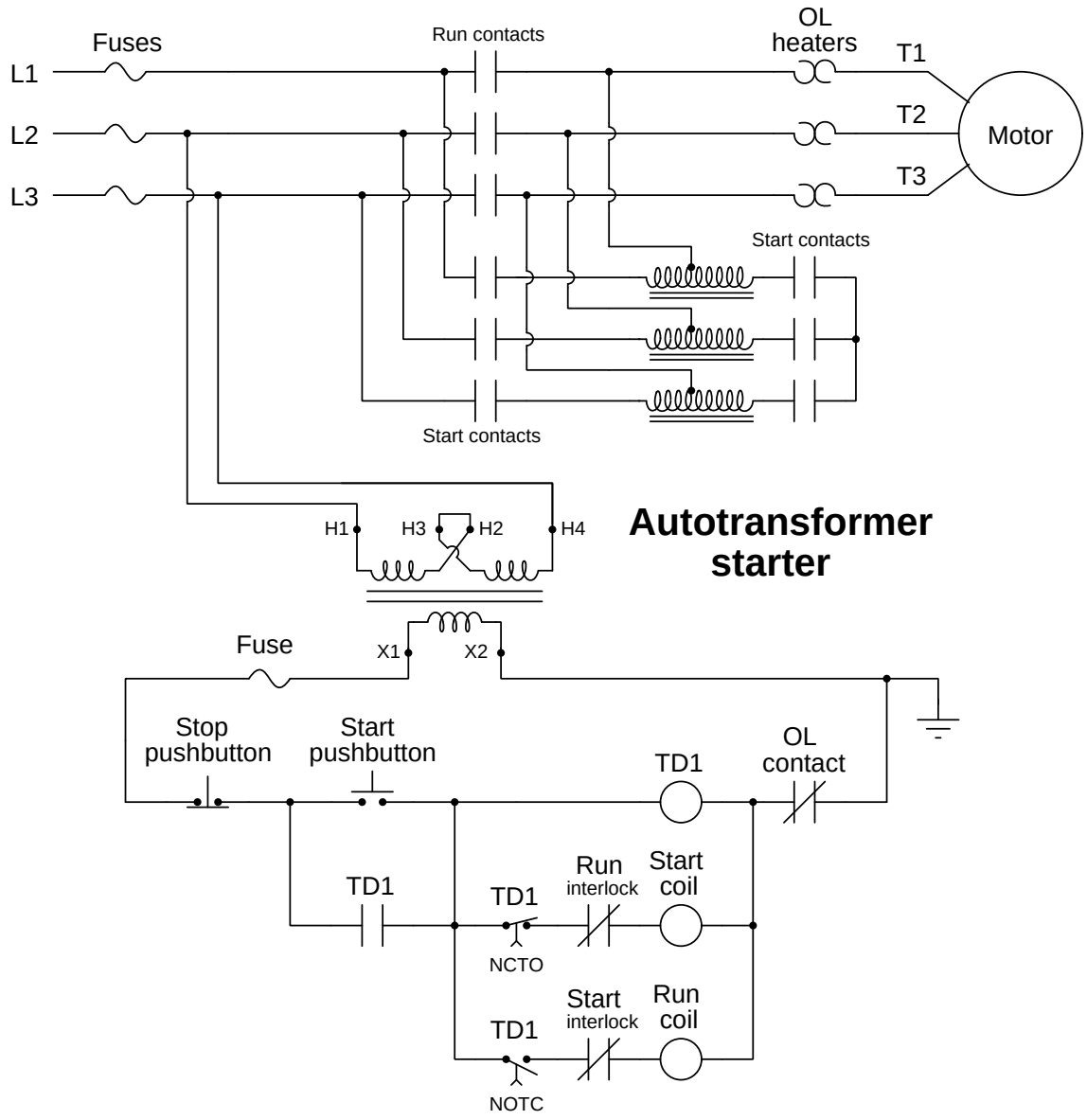
`Grading`

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

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

Problem #2

(Instructor will randomly choose motor base parameters (line voltage, line current, frequency, shaft speed, horsepower), motor efficiency, and time-delay relay TD1 time duration. Assume an autotransformer tap ratio of 50%):



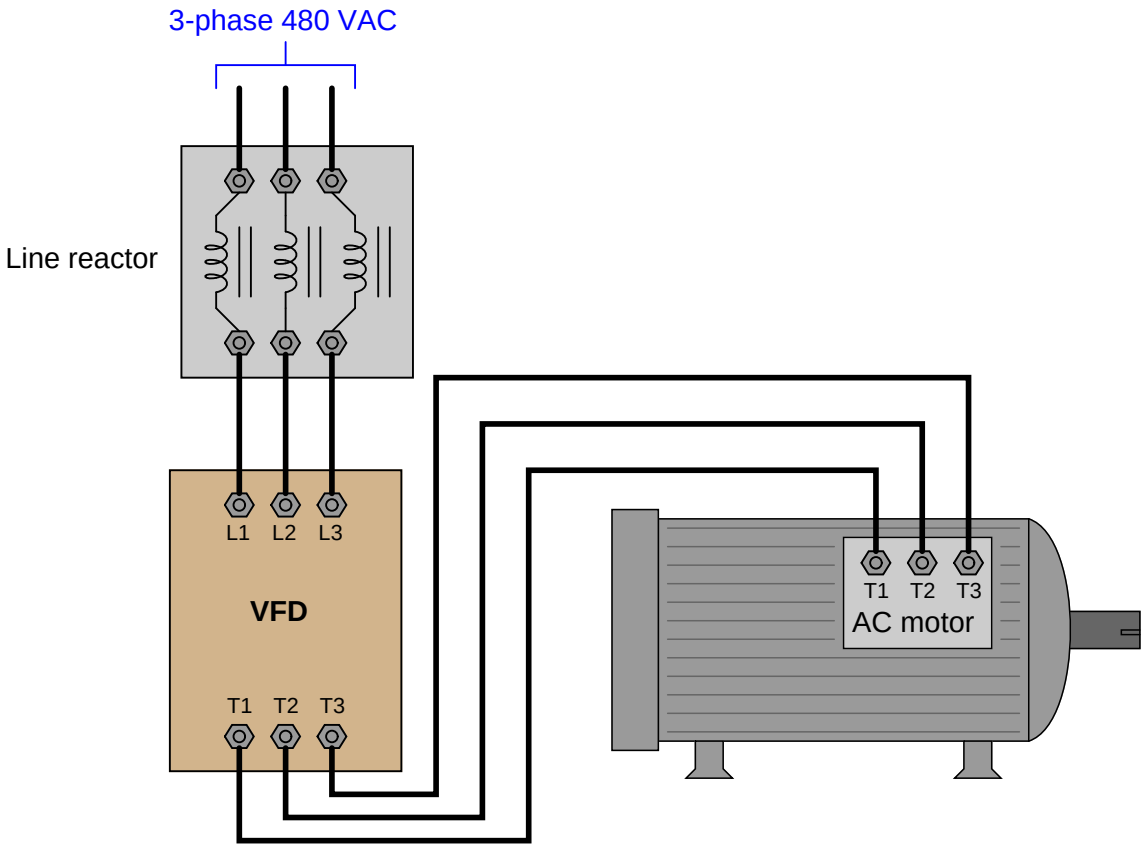
`Grading`

- ◯ [20%] Current through L2 terminal at full motor load (I_{L2}) after TD1 has timed out
- ◯ [20%] Voltage between terminals ____ and ____ at time ____ seconds after pressing "Start"
- ◯ [20%] Status of contact ____ at time ____ seconds after pressing "Start"
- ◯ [20%] Consequence of ____ failing (*open*/*shorted*)
- ◯ [20%] Consequence of ____ failing (*open*/*shorted*)

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

Problem #3

(Instructor will randomly choose motor base parameters (line voltage, line current, frequency, shaft speed, horsepower), line reactor inductance, motor efficiency, and VFD efficiency. Assume a 480 Volt three-phase source frequency of 60 Hz):



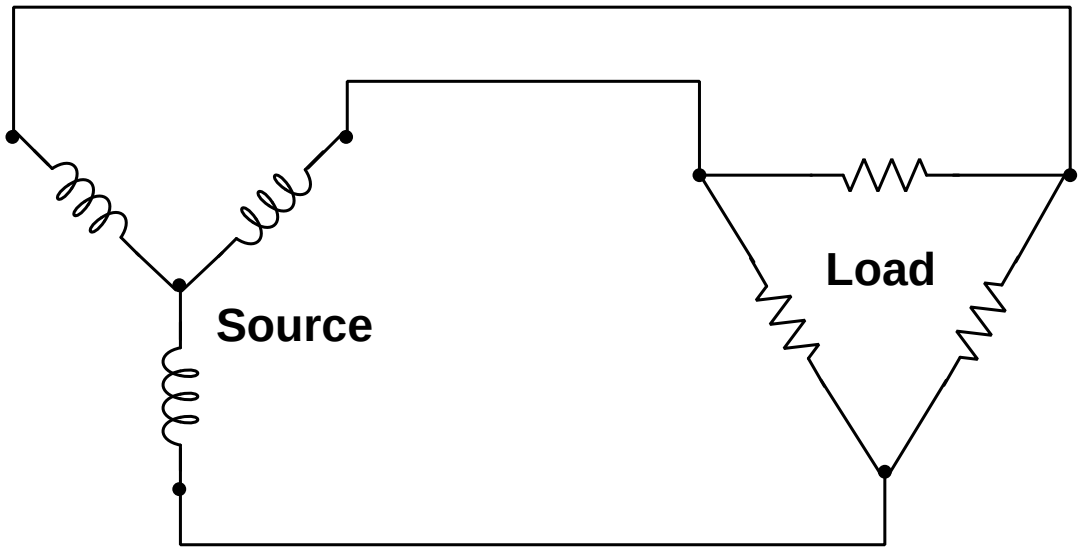
`Grading`

- ◯ [20%] Current through L1 terminal at full motor speed and load (I_{L1})
- ◯ [20%] Current through T3 terminal at full motor speed and load (I_{T3})
- ◯ [20%] VFD output frequency at ____ RPM motor shaft speed
- ◯ [20%] Reactance of L2 line reactor for the fundamental frequency (X_L)
- ◯ [20%] Reactance of L1 line reactor for the fifth harmonic frequency (X_L)

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

Problem #4

(Instructor will randomly choose *two* of the following – I_{line}, I_{phase} (source or load), V_{line}, V_{phase} (source or load), R_{phase} (load), P_{total}):



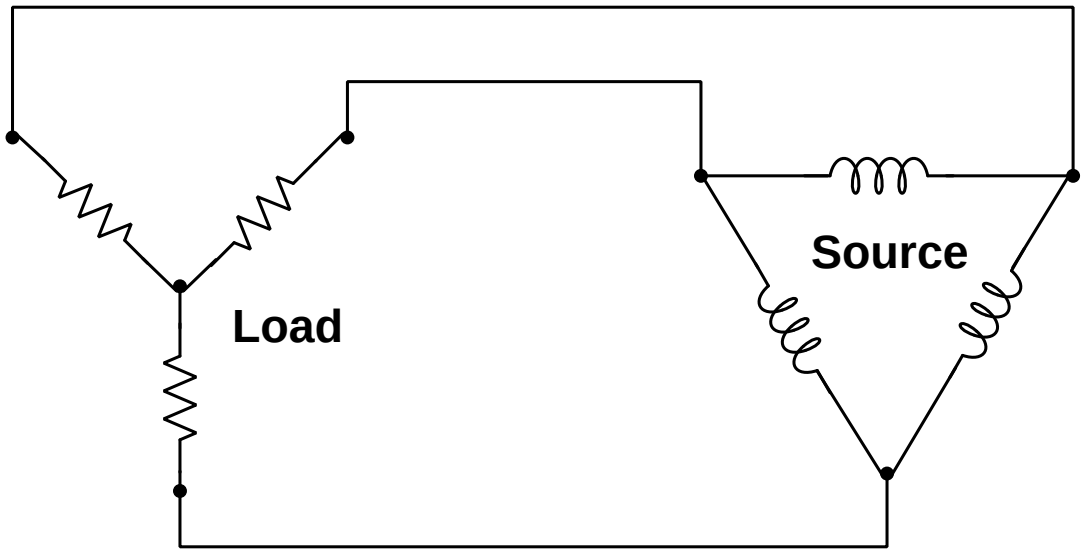
`Grading`

◯ [20% each] Calculate **five** of the unspecified parameters (student's choice)

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

Problem #5

(Instructor will randomly choose *two* of the following – I_{line}, I_{phase} (source or load), V_{line}, V_{phase} (source or load), R_{phase} (load), P_{total}):



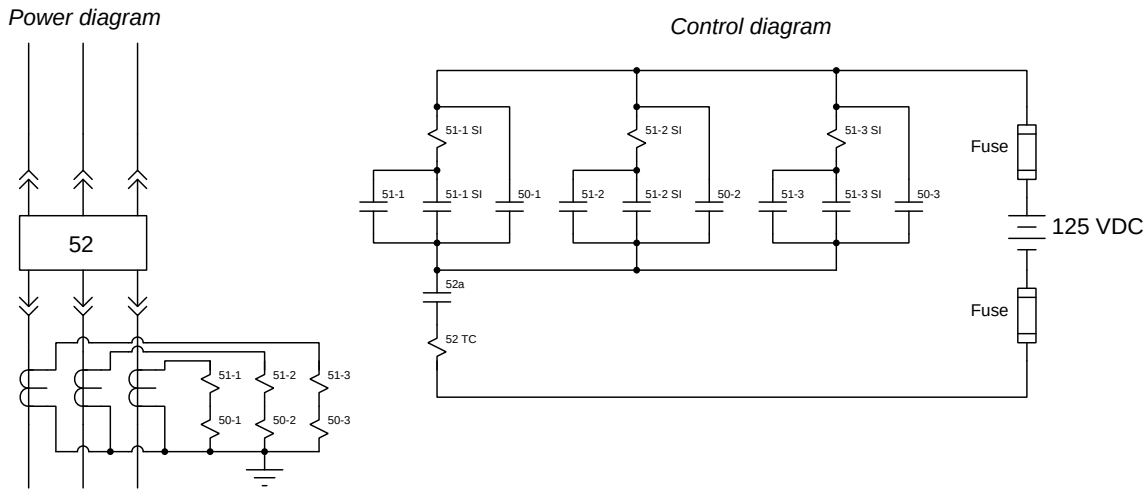
`Grading`

◯ [20% each] Calculate **five** of the unspecified parameters (student's choice)

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

Problem #6

(Instructor will randomly choose CT ratios, line voltage, maximum rated load power, and coil burdens):



CT ratio (each) = _____

V_{line} = _____

P_{load} (max) = _____

50 coil burden (each) = _____

51 coil burden (each) = _____

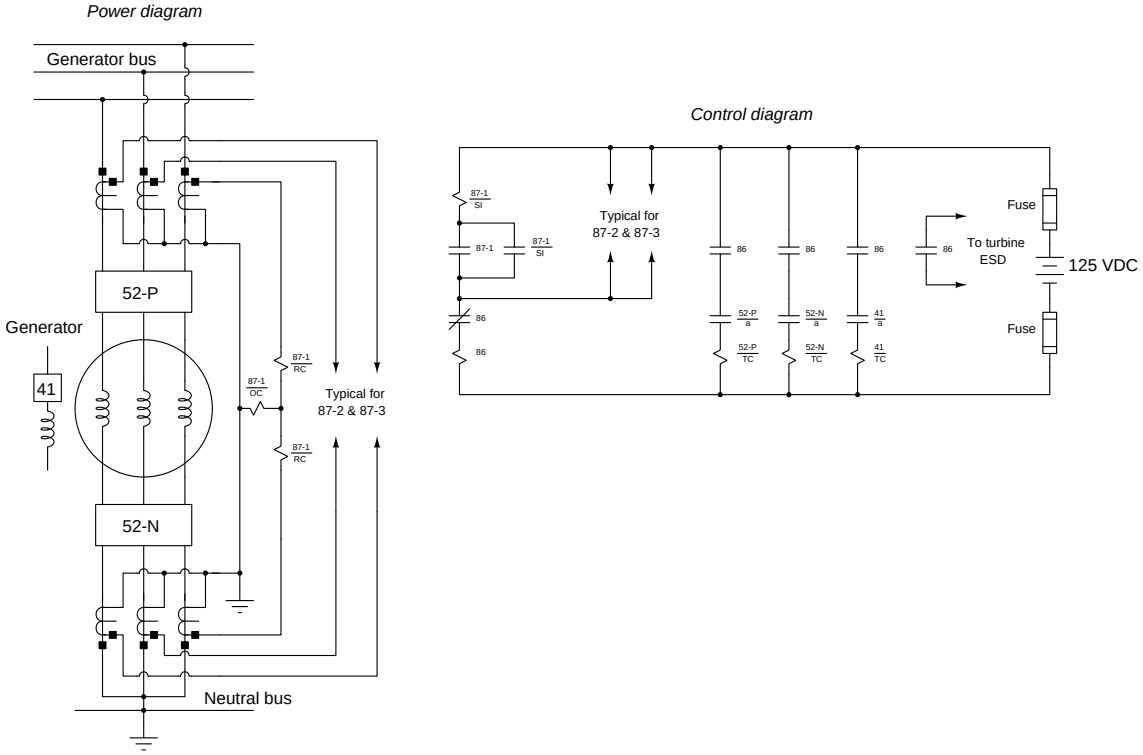
`Grading`

- ◯ [20%] Current magnitude through coil _____ at full load
- ◯ [20%] Voltage magnitude across coil _____ at full load
- ◯ [20%] Instantaneous pick-up current value for relay to trip at $I_{line(fault)}$ = ____ Amperes (answer given in Amperes CT secondary)
- ◯ [20%] Time-overcurrent pick-up current value for relay at maximum rated load power (answer given in Amperes CT secondary)
- ◯ [20%] Consequence of _____ failing (*open*/*shorted*)

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

Problem #7

(Instructor will randomly choose CT ratios, line voltage, maximum rated generator power, and coil burdens):



CT ratio (each) = _____

V_{line} = _____

P_{load} (max) = _____

87/RC coil burden (each) = _____

87/OC coil burden (each) = _____

`Grading`

◯ [20%] Current magnitude through coil _____ at full load (no fault)
◯ [20%] Voltage magnitude across coil _____ at full load
◯ [20%] Current magnitude through coil 87-1/____ at I_{A1} (generator phase A, line side) = ____ Amperes and I_{A2} (generator phase A, neutral side) = ____ Amperes
◯ [20%] Consequence of _____ failing (*open*/*shorted*)
◯ [20%] Consequence of _____ failing (*open*/*shorted*)

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

Theory session 60

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

- (Question #1) Sketch proper wire connections to form a working motor starter circuit.
  Contactor behavior, ladder logic diagrams, three-phase motor control, industrial pushbutton switch function

- (Question #2) Calculate voltage, current, resistance, and/or power in a balanced three-phase AC circuit
  Properties of wye-connected networks, properties of delta-connected networks

- (Question #3) Calculate voltages and/or currents within a three-phase protective relay circuit.
  Properties of wye-connected networks, properties of delta-connected networks, complex numbers, phasor arithmetic, Ohm's Law, KVL, KCL, instrument transformers, 50/51 overcurrent relays, inverse-time trip functions, 87 differential current relays

- (Question #4) Determine possible faults in a protective relay circuit.
  Effects of opens vs. shorts, properties of wye-connected networks, properties of delta-connected networks, overcurrent protection, differential current protection, instrument transformer properties

- (Question #5) Determine possible faults in a motor starter circuit.
  Effects of opens vs. shorts, three-phase AC induction motors, ladder logic diagrams, BJT behavior

file wt_0089