IETTI-104 – AC Circuit Theory (Semester 2 THEORY)

NAME: _____ Last update 11 October 2026

Session	Topic	Journal	P.S.	Comments
Session 01	Intro to the Career			
Session 02	Electrical hazards			
Session 03	Soldering			
Session 04	Capacitance and inductance			
Session 05	Trigonometry			
Session 06	AC quantities and meas.			
Session 07	Phasor mathematics			
Session 08	Oscilloscopes (I)			
Session 09	Oscilloscopes (II)			
Session 10	R, X, Z			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 13	Efficiency / power factor			
Session 14	Series AC circuits			
Session 15	Parallel AC circuits			
Session 16	Resonance			
Session 17	Series-parallel AC circuits (I)			
Session 18	Series-parallel AC circuits (II)			
Session 19	Frequency-domain analysis			
Session 20	Signal coupling / noise			
Session 21	Elementary filter circuits (I)			
Session 22	Elementary filter circuits (II)			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 25	Transformers (I)			
Session 26	Transformers (II)			
Session 27	Phasors and AC measurements			
Session 28	Phasor diagrams			
Session 29	Polyphase AC (I)			
Session 30	Polyphase AC (II)			
Session 31	Polyphase transformers (I)			
Session 32	Polyphase transformers (II)			
Session 33	AC generators			
Session 34	AC motors			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 37	Rectifier circuits			
Session 38	Bipolar junction transistors			
Session 39	Linear voltage regulators			
Session 40	Thermal management			
Session 41	Pulse-width modulation			
Session 42	DC-AC power conversion (I)			
Session 43	DC-AC power conversion (II)			
Session 44	DC-DC power conversion (I)			
Session 45	DC-DC power conversion (II)			
Session 46	Power conditioning/protection			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 49	Combinational logic review			
Session 50	Encoders and decoders			
Session 51	Multiplexers and demultiplexers			
Session 52	Latching logic			
Session 53	Shift registers			
Session 54	Counters			
Session 55	PLC counter instructions			
Session 56	PLC timer instructions			
Session 57	Digital signal integrity (I)			
Session 58	Digital signal integrity (II)			
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 teaches the theory of AC and state-based digital logic circuits with an emphasis on physical conservation laws and other foundational concepts as unifying principles, including AC measurements, series-parallel reactive networks, transformers, harmonics, polyphase AC power systems, power conversion circuits, latch-based digital logic circuits, and programmable logic controller (PLC) counting and timing functions. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

Course learning outcomes

- Compute voltages and currents in AC reactive circuits, passive filter networks, transformer circuits, polyphase power systems, and semiconductor power-conversion circuits, and latching logic 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 filter circuits, transformer circuits, and discrete semiconductor power circuits. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple filter networks, polyphase transformer banks, and AC motor starters to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to AC theory, power conversion, and programmable logic controllers as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in AC reactive circuits, transformer circuits, power conversion circuits, and logic circuits given schematic diagrams and reported symptoms. (Addresses Program Learning Outcomes 5, 6)
- Summarize physical laws and concepts related to AC and latching logic circuits, 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 "What Makes You Marketable?" chapter of the *Career Guide* document
- Read, reflect, and update your Theory Journal on the "Locating Employment" 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*
- 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!*
- Identify the pre-work for *tomorrow's* theory session
- [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)
- "Grading standards for Theory courses" 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

  file wt_1002

Theory session 02

Source text – *Electrical Hazards* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_hazards.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.
- 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 "Safe to touch?" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Shock hazard calculation" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Electrically verifying hot, neutral, and ground" 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_0080

Theory session 03

Source text – *Soldering* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_solder.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 concepts of soldering
  → Soldering metallurgy
  → Soldering flux
  → Soldering safety
  → Hand-soldering
  → Typical solder defects
- Complete "Makeshift soldering heat-sink" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Converting between Celsius and Fahrenheit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Soldering temperature profile" in the Diagnostic Reasoning section of the Questions chapter.

Source text – *NASA Hand Solder Training Slideshow* courtesy of NASA

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

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

- Browse the slideshow to identify several examples of improperly-soldered connections, and explain what is wrong with each one.
- Browse the slideshow to identify several examples of acceptable soldered connections, and explain what is correct with each one.

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_0172

Theory session 04

Source text – *Capacitance and Inductance* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_cl.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 "Controlling the rate of de-energization" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Rail gun capacitor" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Mixed-source circuits with capacitors and inductors" 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_0170

Theory session 05

Source text – *Trigonometry* learning module

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

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

- If you haven't already, purchase a scientific calculator capable of complex-number arithmetic. *The TI-36X Pro is recommended.* Top-end TI calculators (e.g. TI-89) also offer this functionality, but the TI-36X Pro is much cheaper! The TI-83 and TI-84 calculator models can also perform these functions, but they do so in a more clumsy way than either the TI-89 or TI-36X Pro.
- 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 "Radian/degree angle conversions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Plotting sine and cosine functions" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Unknown angles and side lengths" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake(s)" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform right-triangle analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate each diagram with all calculated values to give context to your mathematical work.

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_0181

Theory session 06

Source text – *AC Quantities and Measurements* learning module

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

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

- If you haven't already, purchase a scientific calculator capable of complex-number arithmetic. *The TI-36X Pro is recommended.* Top-end TI calculators (e.g. TI-89) also offer this functionality, but the TI-36X Pro is much cheaper! The TI-83 and TI-84 calculator models can also perform these functions, but they do so in a more clumsy way than either the TI-89 or TI-36X Pro.
- 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 "Wire and insulation sizing" in the Conceptual Reasoning section of the Questions chapter.
- Complete "AC voltage oscillographs" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Phase shift from oscillographs" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Detecting AC mains distortion" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform AC circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0065

Theory session 07

Source text – *Phasor Mathematics* learning module

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

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

- If you haven't already, purchase a scientific calculator capable of complex-number arithmetic. *The TI-36X Pro is recommended.* Top-end TI calculators (e.g. TI-89) also offer this functionality, but the TI-36X Pro is much cheaper! The TI-83 and TI-84 calculator models can also perform these functions, but they do so in a more clumsy way than either the TI-89 or TI-36X Pro.
- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Complete "Practice: complex number calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Simple phasor diagrams" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Series AC voltages" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Incorrect voltage calculation" 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_0066

Theory session 08

Source text – *Oscilloscopes* learning module

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

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

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Run PicoScope software in its "Demo" mode and experiment with measuring the amplitude, period, and frequency of a simulated waveform, and show the final results.
- Complete "Measuring waveform parameters" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Diagnosing incorrect display settings" 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_00182

Theory session 09

Source text – *Oscilloscopes* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_oscope.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:
  → Probes
  → Triggering
  → Differential measurements
  → X-Y mode
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Run PicoScope software in its "Demo" mode and experiment with measuring the trigger settings to see what effect they have on the waveform's display. Be sure to document your results.
- Complete "Uses of a x10 probe" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Measuring motor inrush current" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Frequency ratios" 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_0183

Theory session 10

Source text – *Resistance, Reactance, and Impedance* learning module

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

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

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the "Example circuit #1" section of the Full Tutorial chapter.
- Read, reflect, and update your Theory Journal on the "Example circuit #2" section of the Full Tutorial chapter.
- Read, reflect, and update your Theory Journal on the "Example circuit #3" section of the Full Tutorial chapter.
- Complete "Parasitic inductance and capacitance" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Simple AC circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Identifying an unmarked component" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform AC circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. Feel free to annotate your circuit as though it were DC rather than AC in order to give it definite voltage polarities and current directions. As always, annotation gives context to your mathematical work.

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_0067

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_0191

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**
Reactance and Impedance **Trig. functions** *(e.g. sine, cosine, tangent)* **Complex numbers**
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.

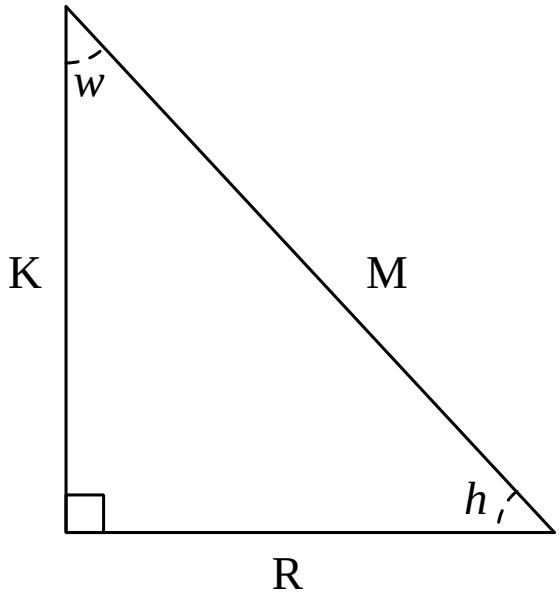
`Grading`

- ◯ [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

(Side lengths and angles randomly chosen by instructor):



`Grading`

- ◯ [20%] Calculate all unspecified side lengths
- ◯ [20%] Calculate all unspecified angles
- ◯ [20%] Demonstrate three different ways to calculate the value of a single angle
- ◯ [20%] Demonstrate three different ways to calculate the value of a single side length
- ◯ [20%] Identify the (*adjacent/opposite*) side relative to angle _____

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

Problem #3

Demonstrate the measurement of an AC signal voltage using an oscilloscope. You may elect to do a live demonstration where you use real test equipment, or you may demonstrate this using a live computer simulation (e.g. Picoscope software in "demo" mode).

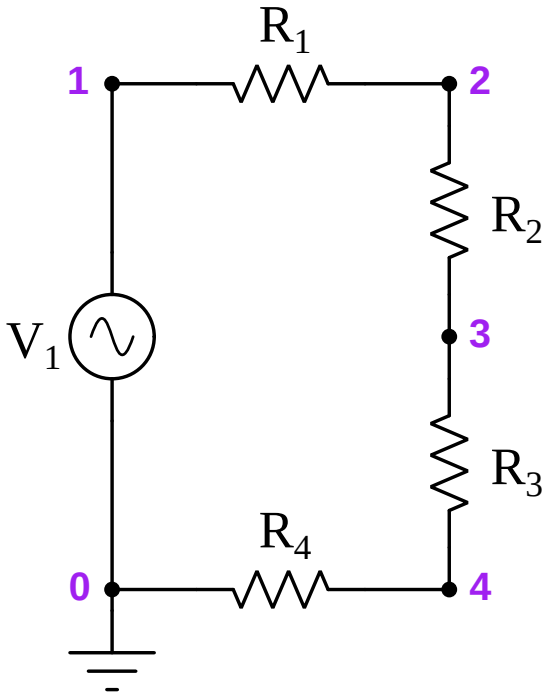
`Grading`

- ◯ [20%] Predict and demonstrate how an (*increase/decrease*) in signal voltage will affect the oscilloscope's view of the signal
- ◯ [20%] Predict and demonstrate how an (*increase/decrease*) in signal frequency will affect the oscilloscope's view of the signal
- ◯ [20%] Demonstrate how to measure the signal's peak-to-peak voltage
- ◯ [20%] Calculate the signal's RMS voltage
- ◯ [20%] Explain and demonstrate how triggering works to to lock a particular point of the waveform on the screen

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

Problem #4

(Component values randomly chosen by instructor; assume an oscilloscope is ready to measure voltages, with its ground clip already connected to node 0):



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.

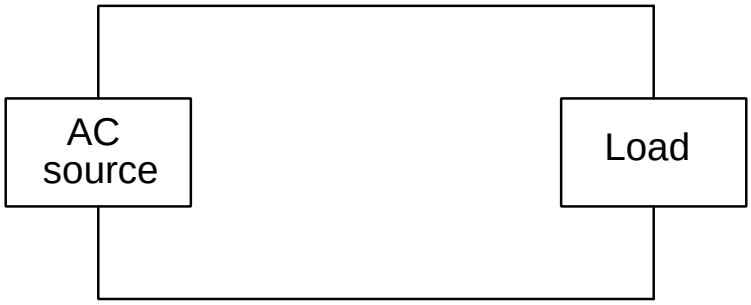
`Grading`

- ◯ [20%] Current magnitude through node 3 (I_3)
- ◯ [20%] Voltage measured by oscilloscope at node _____ with the circuit healthy
- ◯ [20%] Voltage measured by oscilloscope at node _____ with the circuit healthy
- ◯ [20%] Voltage measured by oscilloscope at node _____ with _____ failed open
- ◯ [20%] Voltage measured by oscilloscope at node _____ with _____ failed shorted

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

Problem #5

(Component types and values randomly chosen by instructor; source may be AC voltage or AC current, load may be R, C, or L):



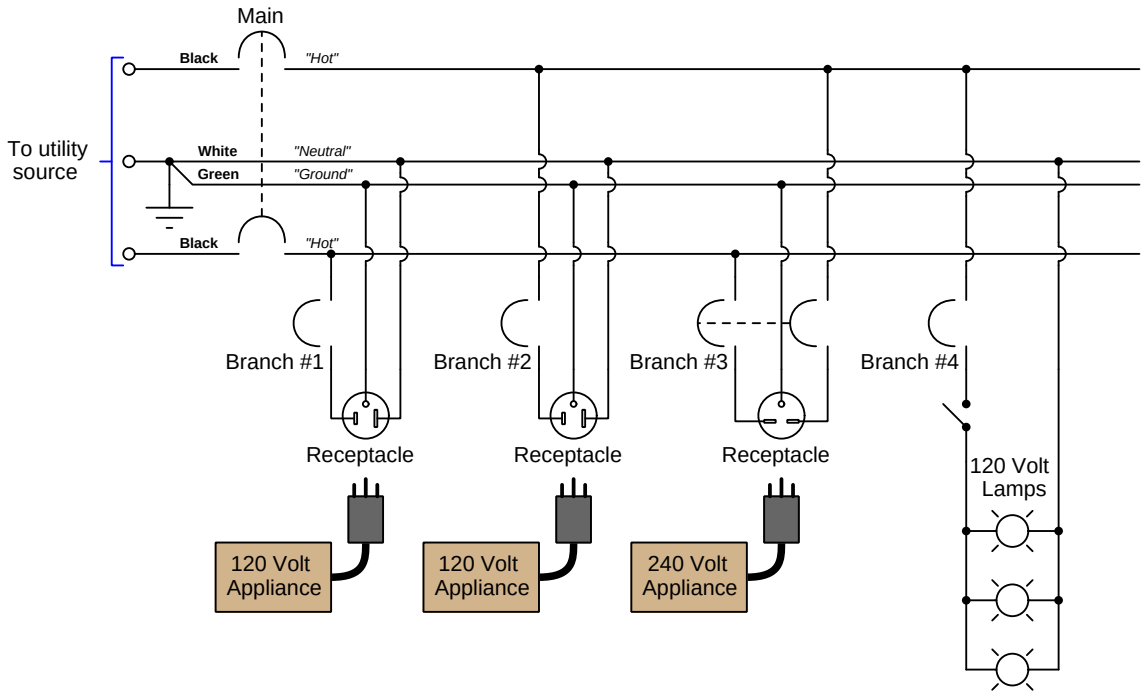
Grading

- ◯ [20%] Reactance of load as a scalar value
- ◯ [20%] Impedance of load as a complex (phasor) value
- ◯ [20%] Current magnitude and phase angle
- ◯ [20%] Voltage magnitude and phase angle
- ◯ [20%] Predict effects of source frequency (*increasing/decreasing*)

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

Problem #6

A simplified schematic diagram of a typical residential 120/240 Volt split-phase electrical system appears below:



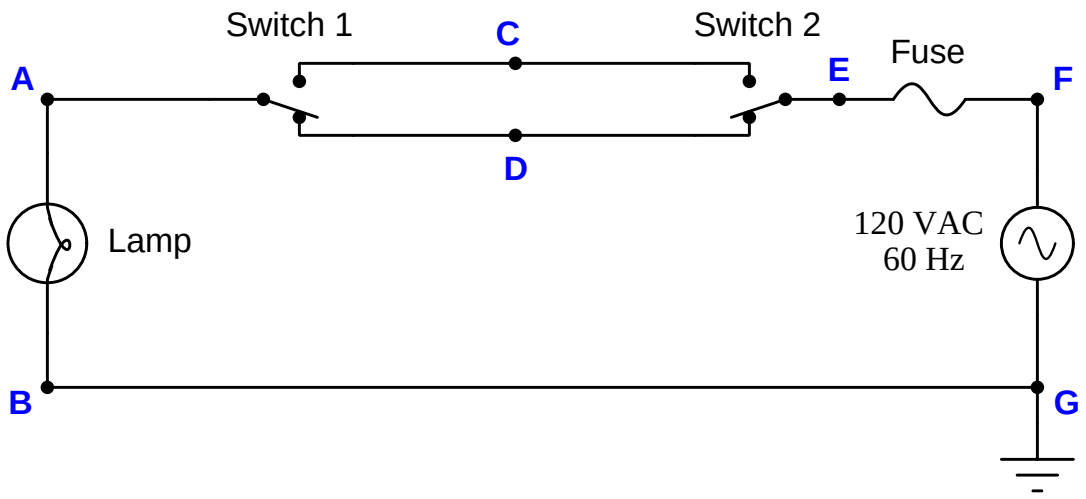
`Grading`

- ◯ [20%] Identify all wires that would be dangerous to touch with all circuit breakers closed
- ◯ [20%] Identify two different places you could measure 120 Volts with a voltmeter
- ◯ [20%] Identify two different places you could measure 240 Volts with a voltmeter
- ◯ [20%] Describe complete lock-out, tag-out and safety verfication procedure for isolating power to receptacle #_____ prior to replacing that receptacle
- ◯ [20%] Trace path of fault current if the appliance plugged into receptacle #_____ develops an internal short-circuit between its hot and (*neutral*/*ground*) conductors

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

Problem #7

(Symptoms and switch positions randomly chosen by instructor):



Fault	Possible	Impossible
Open wire at node C		
Open wire at node D		
Dead source		
Blown fuse		
Lamp failed open		
Lamp failed shorted		
Switch 1 failed open		
Switch 2 failed open		
Open wire between nodes B and G		
Open wire between node G and earth ground		

`Grading`

◯ Percentage of correct possible/impossible selections

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

Problem #8

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

`Grading`

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

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

Theory session 12

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

- (Question #1) 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 #2) Calculate voltages and currents in single-source, single-load AC circuits.
  Ohm's Law, inductive reactance, capacitive reactance, impedance, complex-number arithmetic, polar and rectangular forms of complex numbers, AC phasors

- (Question #3) Identify good versus poor solder connections by photograph.
  Soldering practices

- (Question #4) Identify electrical shock hazards in an AC power circuit schematic.
  Kirchhoff's Laws, electrically common points, transformers, power system grounding, effects of opens vs. shorts

- (Question #5) Apply right-triangle trigonometry to the solution of practical distance problems.
  Pythagorean Theorem, sine and arc-sine functions, cosine and arc-cosine functions, tangent and arc-tangent functions

- (Question #6 – REVIEW) Determine possible faults in an elementary circuit.
  Voltage, current, effects of opens vs. shorts, behavior of sources vs. loads

- (Question #7 – REVIEW) Determine the nominal, low, and high resistance values for four-band resistors given their band colors.
  Resistor 4-band color codes, percentage calculations, tolerance

- (Question #8 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
  Voltage, current, behavior of sources vs. loads, multimeter usage

- (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_0085

Theory session 13

Source text – *Efficiency and Power Factor* learning module

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

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

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Power factor from wattmeter" in the Quantitative Reasoning section of the Questions chapter.
- Complete "AC generator horsepower" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Correcting an arbitrary load's power factor" 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.

  file wt_0197

Theory session 14

Source text – *AC Series Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ac_s.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 "VIZ table for series RC circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "LL and RL phasor diagrams" in the Quantitative Reasoning section of the Questions chapter.
- Identify where to find example circuits with complete solutions worked out for you, for practice. As you've no doubt noticed, there are many details one must master to complete these calculations flawlessly, not the least of being how to use your calculator consistently and effectively, and the only path to mastery is *practice*. Spending hours and hours of time solving these kinds of problems is a necessary part of learning your craft, so let's be sure you have plenty of practice problems ready to go!
- Run at least one simulation of a three-resistor voltage divider (circuit_001) 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.)

NOTE: there are many calculations required to perform AC circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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.
- Modeling series RLC circuits using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions for series AC networks!

  file wt_0184

Theory session 15

Source text – *AC Parallel Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ac_p.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 "VIZ table for parallel RC circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "LL and RL phasor diagrams" in the Quantitative Reasoning section of the Questions chapter.
- Identify where to find example circuits with complete solutions worked out for you, for practice. As you've no doubt noticed, there are many details one must master to complete these calculations flawlessly, not the least of being how to use your calculator consistently and effectively, and the only path to mastery is *practice*. Spending hours and hours of time solving these kinds of problems is a necessary part of learning your craft, so let's be sure you have plenty of practice problems ready to go!
- Run at least one simulation of a three-resistor current divider (circuit_002) 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.)

NOTE: there are many calculations required to perform AC circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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.
- Modeling parallel RLC circuits using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions for parallel AC networks!

  file wt_0185

Theory session 16

Source text – *Resonance* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_resonance.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 "Resonant pulse circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Series LC circuit calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Deriving the resonant frequency equation" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the Mistake(s)" 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_0070

Theory session 17

Source text – *Series-parallel AC circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ac_sp.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.
- Complete "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Series and parallel network impedances" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Series-parallel circuit tables" in the Quantitative Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform AC circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

Theory Session Expectations:

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

`Additional resources:`

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

  file wt_0069

Theory session 18

Source text – *Series-parallel AC circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ac_sp.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 "Voltage drop in an RC sub-network" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Induction motor model" in the Quantitative Reasoning section of the Questions chapter.
- 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.

Theory Session Expectations:

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

`Additional resources:`

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

  file wt_0081

Theory session 19

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
  → Building a square wave from sine waves
  → Time vs. frequency in circuits
  → Time-frequency relationships
  → Applications for frequency-domain analysis
- Run PicoScope software in its "Demo" mode and experiment with the spectrum analyzer feature:
  → Display the spectrum of a pure sine wave
  → Alter the frequency of that pure sine wave and note its effect on the spectrum display
  → Display the spectrum of a square wave
  → Display the spectrum of a triangle wave
- Complete "Amplifier test" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Discerning even/odd harmonics from the time domain" 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_0038

Theory session 20

Source text – *Signal Coupling and Noise* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_noise.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:
  → Signal coupling and cable separation
  → Electric field (capacitive) de-coupling
  → Magnetic field (inductive) de-coupling
- Examine and reflect on the Example: capacitive coupling within cable section of the Case Tutorial chapter, and answer the following questions:
  → Identify conditions that would maximize coupling between the aggressor and the victim
  → How would an open fault in the lamp affect the meter's measurement, if at all?
- Examine and reflect on the Example: inductive coupling within cable section of the Case Tutorial chapter, and answer the following questions:
  → Identify conditions that would maximize coupling between the aggressor and the victim
  → How would an open fault in the lamp affect the meter's measurement, if at all?
- Complete "Phantom voltage measurements" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Compressor system wiring" 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_0145

Theory session 21

Source text – *Elementary Filter Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_filters.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:
  → Signal separation
  → Reactive filtering
  → Bode plots
  → LC resonant filters
  → Roll-off
  → Mechanical-electrical filters
  → Summary of filter types
  → Filtering complex signals
- Complete "Identifying (more) filter types" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Filter type and cutoff identifications" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, run at least one simulation of a band-pass filter (Circuit_010) using `tshoot` software during class time.
  → 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.)
  → Run a simulation using the `-nofault` start-up option and use measurements of filter output voltage to generate a Bode plot for a healthy filter network

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_0073

Theory session 22

Source text – *Elementary Filter Circuits* learning module

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

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

- Read, reflect, and update your Theory Journal on the Wave screens section of the Historical References chapter.
- Read, reflect, and update your Theory Journal on the Capacitor parasitics section of the Derivations and Technical References chapter.
- Read, reflect, and update your Theory Journal on the Inductor parasitics section of the Derivations and Technical References chapter.
- Complete "Square wave to sine wave" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Simple harmonic analyzer" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Designing simple RC low-pass and high-pass filters" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, run at least one simulation of a band-pass filter (Circuit_010) using `tshoot` software during class time.
  - → 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.)
  - → Run a simulation using the `-nofault` start-up option and use measurements of filter output voltage to generate a Bode plot for a healthy filter network

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_0171

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 $R_1 = 1.5$ kΩ, $C_1 = 0.33$ μF, $L_1 = 500$ mH, and the source is 12 Volts AC at 500 Hz):

```
* Netlist
v1 2 1 ac 12
r1 2 0 1500
c1 2 0 0.33e-6
l1 1 0 500e-3
.control
set units=degrees
.endc
.ac lin 1 500 500
.print ac vm(2) vp(2)
.print ac vm(0,1) vp(0,1)
.end
```

file wt_0192

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
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.

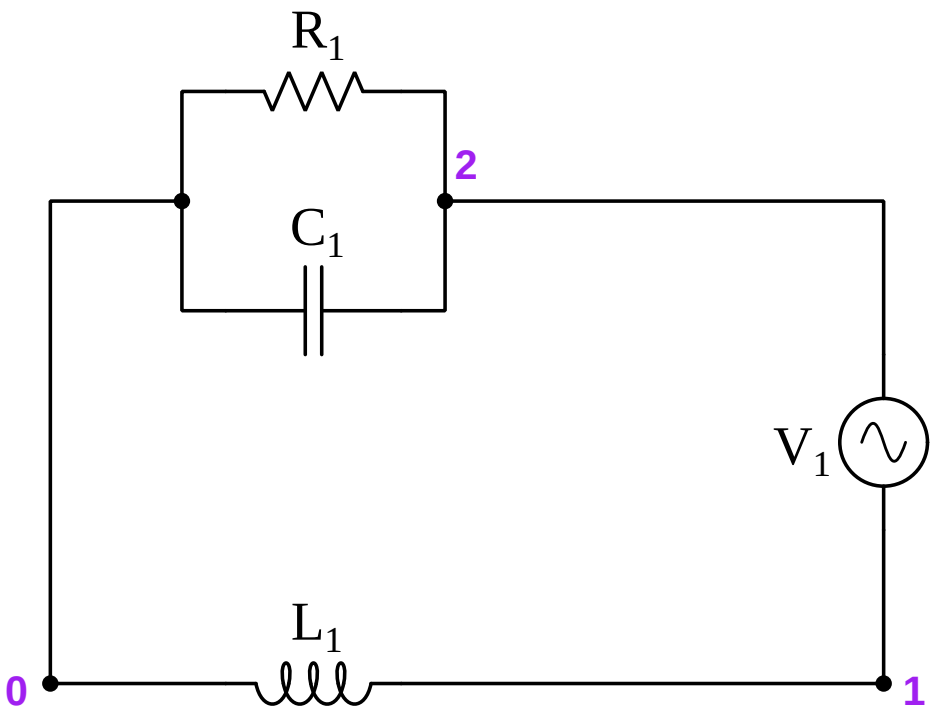
`Grading`

◯ [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):



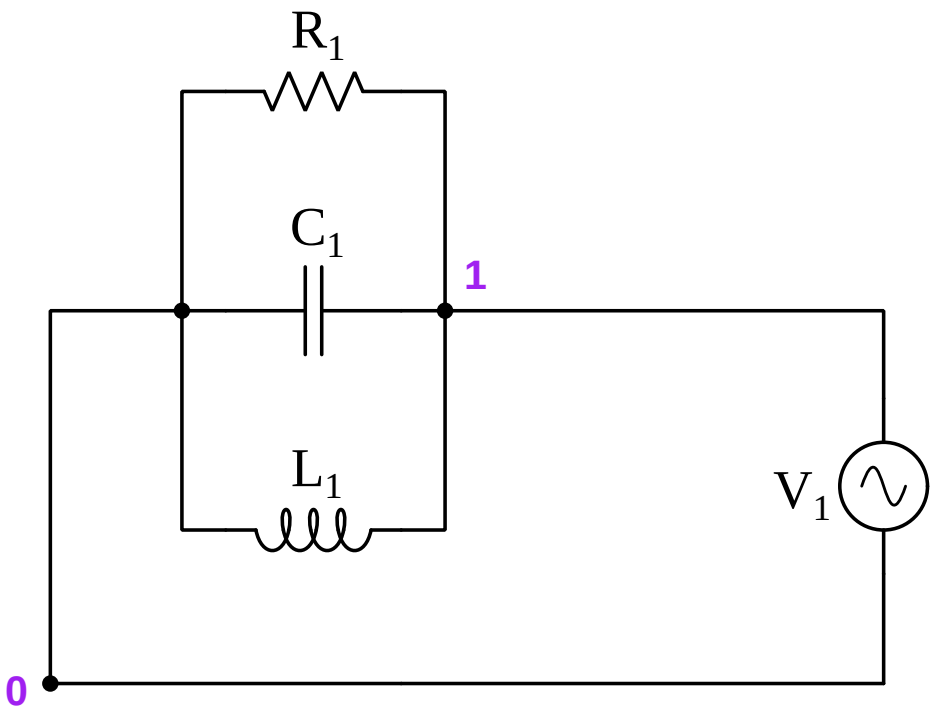
`Grading`

- ◯ [20%] Current magnitude and phase angle through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and phase angle through capacitor C_1 (I_{C1})
- ◯ [20%] Current magnitude and phase angle through inductor L_1 (I_{L1})
- ◯ [20%] Voltage magnitude and phase angle between nodes 2 and 0 (V_{2-0})
- ◯ [20%] Power factor

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

Problem #3

(Component values randomly chosen by instructor):



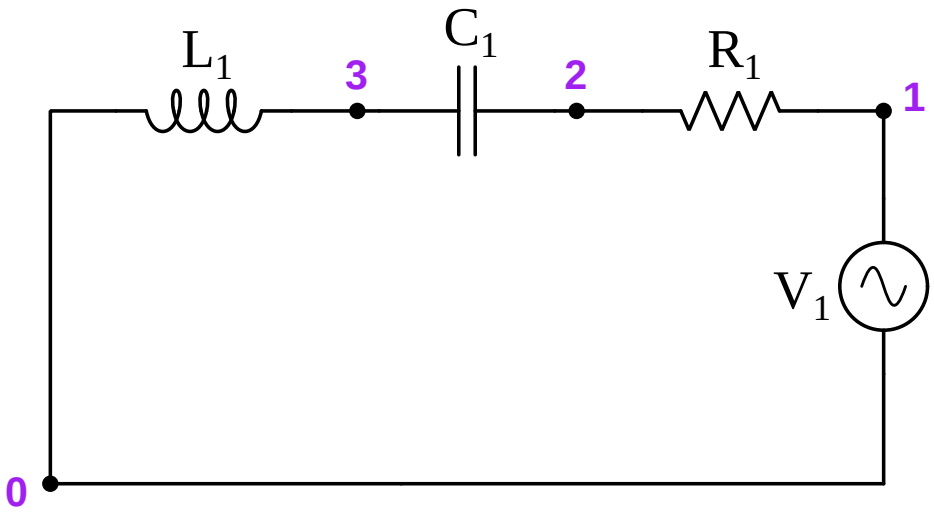
`Grading`

- ◯ [20%] Current magnitude and phase angle through resistor R_1 (I_{R1})
- ◯ [20%] Current magnitude and phase angle through capacitor C_1 (I_{C1})
- ◯ [20%] Current magnitude and phase angle through inductor L_1 (I_{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 #4

(Component values randomly chosen by instructor):



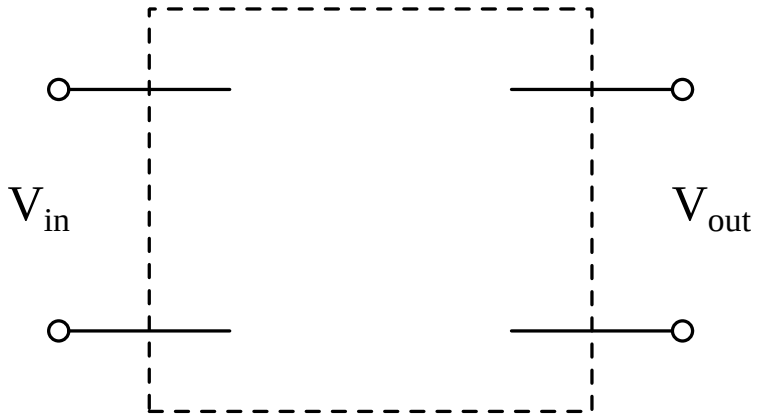
`Grading`

- ◯ [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 #5

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
- Maximum input impedance = _____ Ohms @ cut-off

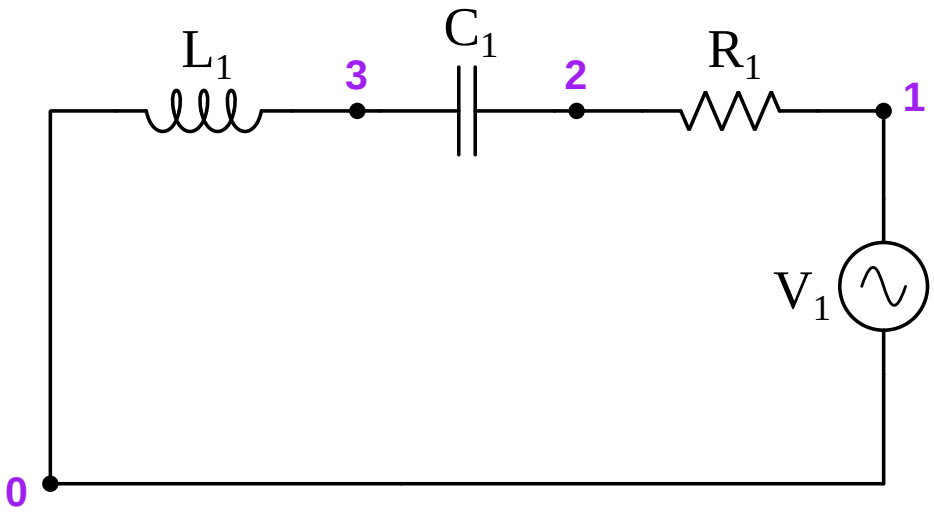
`Grading`

◯ [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 #6

(Component values randomly chosen by instructor):



`Grading`

- ◯ [20%] Calculate resonant frequency with specified component values
- ◯ [20%] Voltage across R_1 (V_{R1}) at resonance
- ◯ [20%] Voltage across C_1 (V_{C1}) at resonance
- ◯ [20%] Voltage across L_1 (V_{L1}) at resonance
- ◯ [20%] Select new value for _____ to resonate at _____ Hz

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

Problem #7

Demonstrate the measurement of signals in both the time and frequency domains. You may elect to do a live demonstration where you use real test equipment, or you may demonstrate this using a live computer simulation (e.g. Picoscope software in "demo" mode).

`Grading`

- ◯ [20%] Predict and then demonstrate how an (*increase/decrease*) in signal amplitude will affect both time- and frequency-domain views of a signal
- ◯ [20%] Predict and then demonstrate how an (*increase/decrease*) in fundamental signal frequency will affect both time- and frequency-domain views of a signal
- ◯ [20%] Predict and then demonstrate signal wave-shapes that contain both even and odd harmonics
- ◯ [20%] Predict and then demonstrate signal wave-shapes that contain only odd harmonics
- ◯ [20%] Predict and then demonstrate the harmonic frequency values for a _____ wave with a fundamental frequency of _____ Hz

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

Problem #8

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

`Grading`

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

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

Theory session 24

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

- (Question #1) Calculate voltages, currents, and impedances in a series AC circuit.
  Properties of series networks, Ohm's Law, Kirchhoff's Laws, AC phasors

- (Question #2) Calculate voltages, currents, and impedances in a parallel AC circuit.
  Properties of parallel networks, Ohm's Law, Kirchhoff's Laws, AC phasors

- (Question #3) 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 #4) Calculate the power factor of an AC circuit.
  Capacitive reactance, inductive reactance, impedance, power factor, apparent power, reactive power, true power, power "triangle", Joule's Law

- (Question #5) Design and sketch a passive filter circuit with a specified cutoff frequency and characteristic.
  Filter circuit behavior, capacitive reactance, inductive reactance, resonance

- (Question #6) Identify a passive filter circuit characteristic from its schematic diagram, and predict the effects of a component fault on that characteristic.
  Properties of series networks, properties of parallel networks, effects of opens vs. shorts, filter circuit behavior, capacitive reactance, inductive reactance

- (Question #7 – REVIEW) Calculate voltage, current, resistance, and/or power in a simple circuit given necessary as well as extraneous parameters.
  Ohm's Law, Joule's Law, resistor 4-band color codes

- (Question #8 – REVIEW) Identify voltage polarity given current direction, and current direction given voltage polarity, for both sources and loads. Also, identify sources versus loads given voltage polarity and current direction.
  Voltage, current, behavior of sources vs. loads

- (Question #9 – REVIEW) Determine necessary resistor value to balance a bridge circuit, as well as calculate voltages and currents in that balanced bridge circuit.
  Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of bridge networks

file wt_0086

Theory session 25

Source text – *Transformers* learning module

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

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

- Read, reflect, and update your Theory Journal on the Simplified Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Prototype electrical power transmission system section of the Historical References chapter.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Industrial control power transformer" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Basic transformer calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Transformer-resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted transformer-lamp 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.

file wt_0071

Theory session 26

Source text – *Transformers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_transformer.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:
  → Loading effects
  → Winding polarity
  → Impedance transformation
- Read, reflect, and update your Theory Journal on the Manufacturing shell-type transformers section of the Derivations and Technical References chapter.
- Read, reflect, and update your Theory Journal on the Manufacturing toroidal transformers section of the Derivations and Technical References chapter.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Gaulard and Gibbs transformer" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Autotransformer currents" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Testing transformer polarity" 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_0186

Theory session 27

Source text – *Phasors and AC Circuit Measurements* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_phasor_measure.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.
- Complete "Boost/buck transformer circuits" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltages between specified points" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake(s)" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform phasor analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0187

Theory session 28

Source text – *Phasor Diagrams* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_phasor_diagram.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 "Explaining the meaning of calculations" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Three parallel current sources" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistakes" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform phasor analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0188

Theory session 29

Source text – *Polyphase AC* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_polyphase.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:
  → Multi-phase AC generators
  → Wye and Delta connections
  → Wye and Delta grounding
  → Three-phase rectification
- Examine and reflect on the Example: wye-wound versus delta-wound motors section of the Case Tutorial chapter, and answer the following questions:
  → Identify which parameters are different between these two electric motors of equal horsepower, when energized by identical three-phase sources.
  → Identify how each of the phase voltages and currents may be calculated from the given information (100 HP, V_{line} = 460 V).
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Balanced Delta source and Wye load" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Balanced Wye source and Delta load" in the Quantitative Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform polyphase circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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 Power 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_0072

Theory session 30

Source text – *Polyphase AC* learning module

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

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

- Read, reflect, and update your Theory Journal on the Prototype electrical power transmission system section of the Historical References chapter.
- Complete "Similar voltages and currents" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Balanced Delta source and Delta load" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Three-phase versus single-phase power transmission" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

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

`Additional resources:`

- The Gallery chapter of the SPICE Modeling of Power 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_0189

Theory session 31

Source text – *Polyphase Transformer Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_polyphase_transformer.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:
  → Review of polyphase networks
  → Wye-Wye transformer bank
  → Delta-Delta transformer bank
  → Wye-Delta transformer bank
  → Delta-Wye transformer bank
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "480 Volts to 208 Volts" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Balanced Wye source and Wye load with transformers" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Failed transformer winding" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform polyphase circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0199

Theory session 32

Source text – *Polyphase Transformer Circuits* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_polyphase_transformer.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:
  → Wiring from phasor diagrams
- Complete "Sketching winding connections" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Pole-mounted transformers" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Load calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake(s)" 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_0200

Theory session 33

Source text – *AC Generators* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_acgen.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 "Induced voltage in stator winding" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Poles and speed and frequency" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of faults in manually-regulated generator" 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_0201

Theory session 34

Source text – *AC Motors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_acmotor.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 "9-lead Wye motor connections" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Motor power based on PT and CT measurements" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of faults in a capacitor-start motor" 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_0190

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_0193

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**
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.

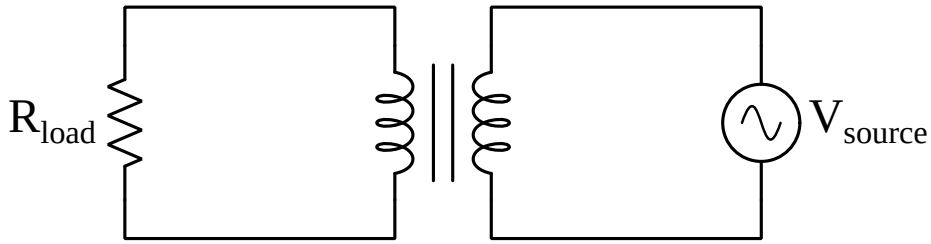
`Grading`

◯ [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):



- V_{source} = _____
- R_{load} = _____
- N_p (primary turns) = _____
- N_s (secondary turns) = _____

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.

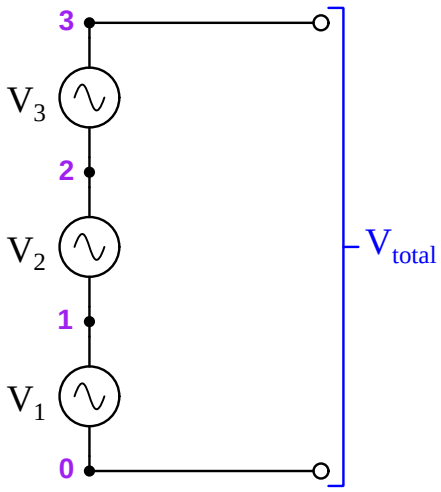
`Grading`

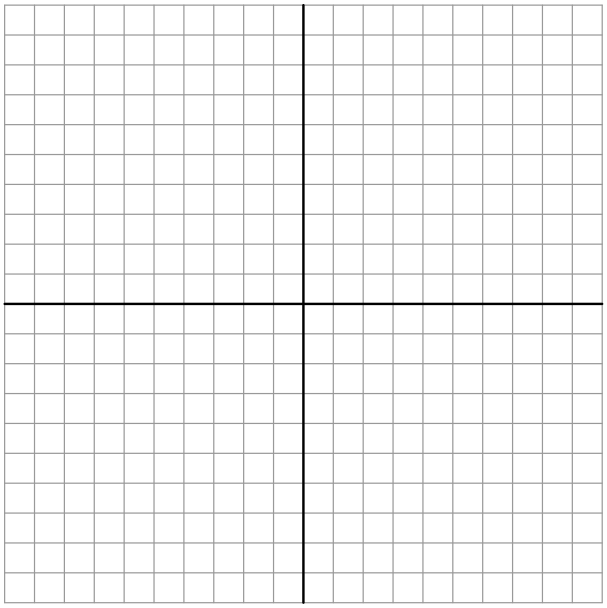
◯ [20%] Current magnitude through primary winding (I_p)
◯ [20%] Current magnitude through secondary winding (I_s)
◯ [20%] Voltage magnitude across load (V_{load})
◯ [20%] Power delivered by source (P_{source})
◯ [20%] Effect(s) of _____ failing open

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

Problem #3

(Source voltages and terminal polarities randomly chosen by instructor):





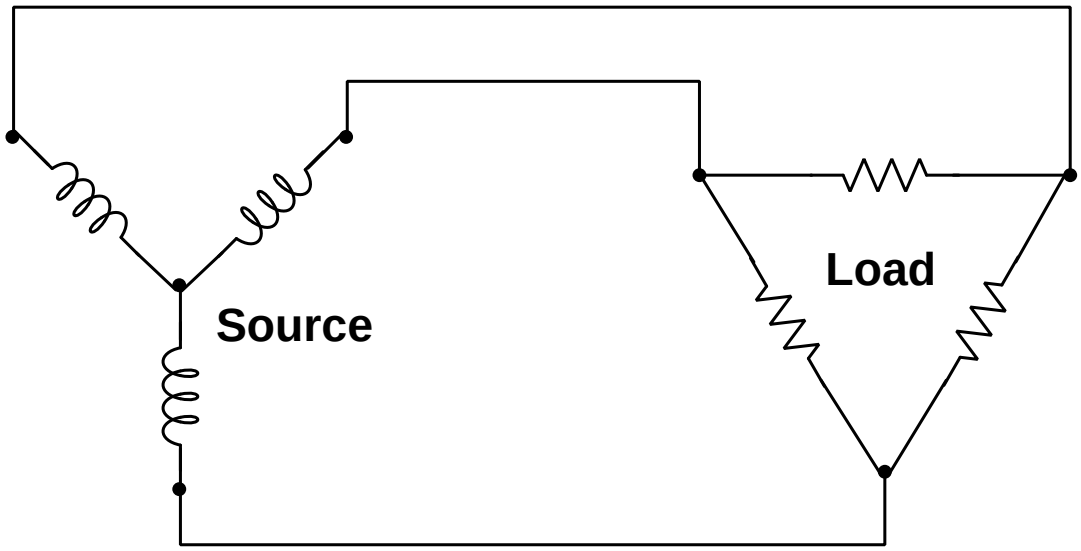
`Grading`

- ◯ [20%] Properly position each source vector on the graph
- ◯ [20%] Calculate V_{total} using a calculator
- ◯ [20%] Properly sketch V_{total} vector on the graph
- ◯ [20%] Re-sketch diagram for source _____ failing (0 Volts)
- ◯ [20%] Re-calculate V_{total} for source _____ failing (0 Volts)

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}). Assume *balanced* conditions throughout the circuit:



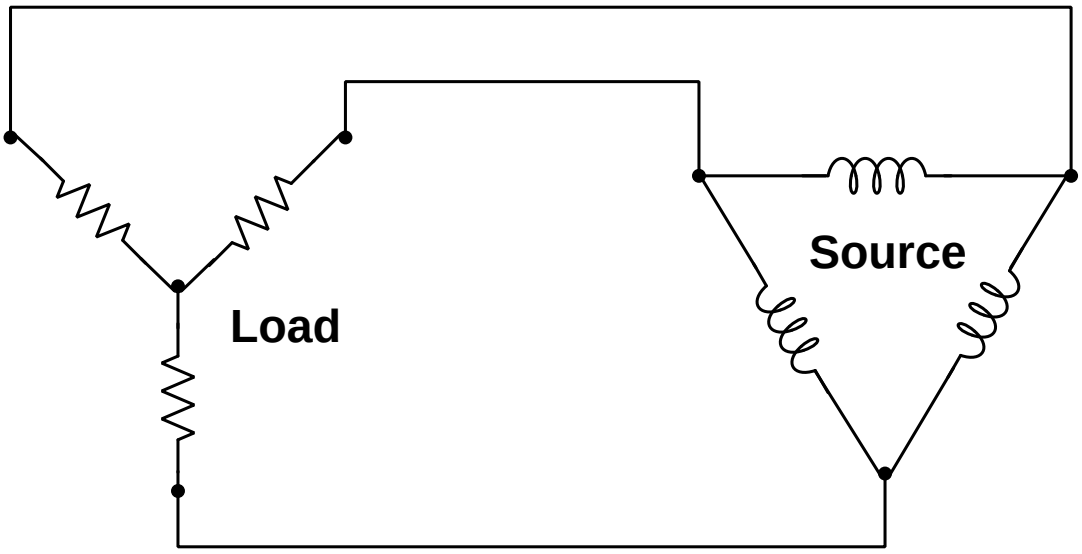
`Grading`

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

Note: full credit given only for answers that are correct <u>and</u> 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}). Assume *balanced* conditions throughout the circuit:



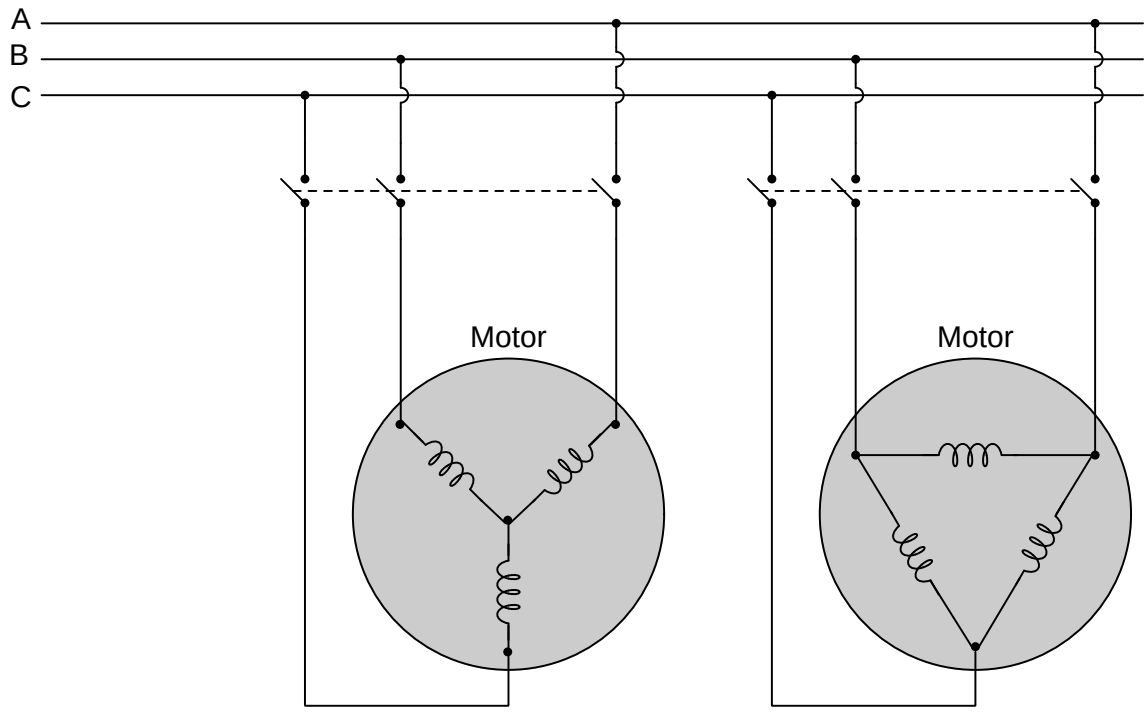
`Grading`

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

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

Problem #6

(Instructor will randomly choose V_{line} and either I_{line}, I_{phase}, or P_{motor} for each of the two motors). Assume *balanced* conditions throughout the circuit:



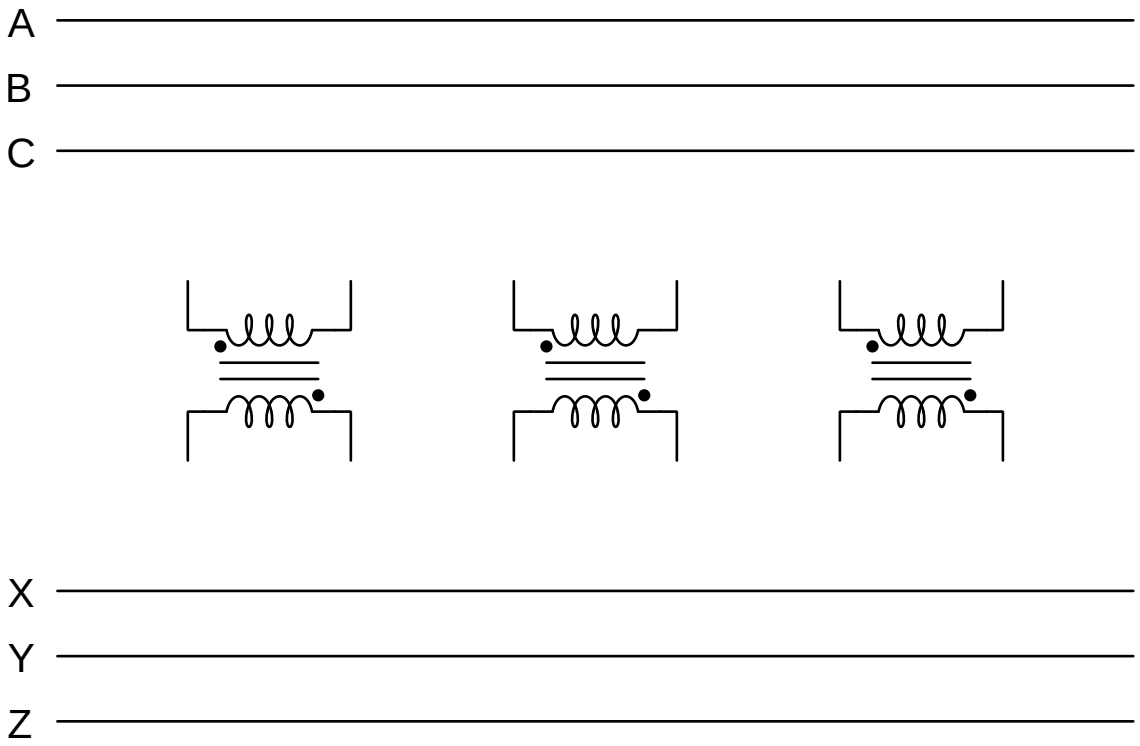
`Grading`

- ◯ [20%] Calculate first unspecified parameter of the Wye motor
- ◯ [20%] Calculate second unspecified parameter of the Wye motor
- ◯ [20%] Calculate first unspecified parameter of the Delta motor
- ◯ [20%] Calculate second unspecified parameter of the Delta motor
- ◯ [20%] Calculate total power for both motors (P_{total})

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

Problem #7

(ABC line voltage and transformer turns ratio randomly chosen by instructor, as well as whether the primaries will be Wye or Delta, and whether the secondaries will be Wye or Delta). Assume *balanced* conditions throughout the circuit:



`Grading`

- ◯ [20%] Proper connections from primary windings to ABC lines
- ◯ [20%] Proper connections from secondary windings to XYZ lines
- ◯ [20%] XYZ line voltage magnitude
- ◯ [20%] Primary winding voltage magnitude
- ◯ [20%] Secondary winding voltage magnitude

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) Calculate voltages, currents, and/or powers in a transformer circuit
  Transformer behavior, Ohm's Law, Joule's Law

- (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) Sketch connections to make a three-phase transformer bank from three separate transformers, given phasor diagrams of primary and secondary voltages.
  Transformer behavior, properties of wye-connected networks, properties of delta-connected networks, phasor diagrams

- (Question #4) Calculate current, horsepower, and/or power factor for an AC electric motor, either single-phase or three-phase.
  Power factor, Joule's Law, properties of wye-connected networks, properties of delta-connected networks

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

- (Question #6) Determine possible faults in a simple AC motor or generator circuit.
  Effects of opens vs. shorts, properties of wye-connected networks, properties of delta-connected networks, AC induction motor behavior, AC generator behavior

- (Question #7 – 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

- (Question #8 – REVIEW) Calculate voltages, currents, and/or power dissipations in a circuit containing multiple sources.
  Properties of series and parallel networks, behaviors of sources and loads, Ohm's Law, Joule's Law, Kirchhoff's Laws, Maximum Power Transfer Theorem, Superposition Theorem, Thévenin's Theorem, Norton's Theorem

- (Question #9 – REVIEW) Design and sketch a circuit exhibiting a specified time delay for inverse-exponential growth or decay of voltage or current.
  Properties of series and parallel networks, capacitor behavior, inductor behavior, inverse exponential calculations

file wt_0087

Theory session 37

Source text – *Rectifier Circuits* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Mercury arc rectifiers section of the Historical References chapter.
- Complete "Terminal block construction of a bridge rectifier" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Rectified peak voltage and ripple frequency" in the Quantitative Reasoning section of the Questions chapter.
- Complete "How not to connect an oscilloscope to a rectifier" 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:`

- Full-wave bridge rectifier with ideal diodes section of the Animations chapter.
- Full-wave bridge rectifier with real diodes section of the Animations chapter.
- The Gallery chapter of the SPICE Modeling of Semiconductor 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_0016

Theory session 38

Source text – *Bipolar Junction Transistors* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_bjt.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.
- Watch the flip-book animation shown in the Animation of an NPN BJT turning on section of the Animations chapter, and answer the following questions:
  - → BJTs control electrical conductivity using the principle of *charge carrier injection*. Describe where and when this phenomenon occurs in the BJT illustration shown in this animation, and what factor(s) prompt it to occur.
  - → Describe/illustrate how a PNP transistor animation would differ from the one shown which is NPN.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "BJT patent" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Controlling and controlled currents" in the Conceptual Reasoning section of the Questions chapter.
- Complete "BJT circuit calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in test circuit" in the Diagnostic Reasoning section of the Questions chapter.

Discuss as a group your learning experience studying bipolar junction transistors 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:`

- The Gallery chapter of the SPICE Modeling of Semiconductor 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_0194

Theory session 39

Source text – *Linear Voltage Regulators* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_linvreg.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 "Manual voltage regulation" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Zener current with varying load resistance" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of faults in a series voltage regulator" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to perform transistor circuit analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0023

Theory session 40

Source text – *Thermal Management* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_thermal.pdf`
EET Reference collection – `EETREF/Datasheets`

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 "Satellite electronics" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Transistor without a heat sink" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake(s)" in the Diagnostic Reasoning section of the Questions chapter.
- Locate a power device datasheet (e.g. power transistor, rectifying diode, voltage regulator, etc. found in the `Datasheets/` directory of your EETREF document collection) and identify relevant thermal management information about that device.
- Locate a heat sink datasheet from an online manufacturer or vendor and identify relevant thermal management information about it.

NOTE: there are many calculations required to perform heat-transfer analysis, and therefore many places one can make mistakes. Here are some proven strategies for success:

- Work through the representative example problems shown in the text, on your own, until your answers match the text's. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results so you do not lose track of each number's meaning. A good way to do this is to thoroughly annotate the circuit diagram with all calculated voltages and currents, including voltage polarities and current directions. This gives context to your mathematical work.

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_0132

Theory session 41

Source text – *Pulse Width Modulation* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_pwm.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.
- Watch the flip-book animation shown in the Comparator generating PWM waveform section of the Animations chapter.
- Complete "Comparator output waveform" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Duty cycle and power calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Identifying possible faults in a motor speed controller" 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_0144

Theory session 42

Source text – *DC-AC Power Conversion* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_dc2ac.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 "Bright/Royer externally-excited inverter circuits" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Converter efficiency" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Tracing fault current" 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_0205

Theory session 43

Source text – *DC-AC Power Conversion* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_dc2ac.pdf`

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

- Watch the flip-book animation shown in the Three-phase converter transistor switching sequence section of the Animations chapter.
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Early three-phase inverter design" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Voltmeter discrepancy" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Faults in a VFD 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.

file wt_0206

Theory session 44

Source text – *DC-DC Power Conversion* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_dc2dc.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:
  → Matching source and load voltages
  → Capacitor and inductor review
  → Simple step-down converter
  → Buck converter
  → Boost converter
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Complete "Buck converter regulation" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Converter efficiency calculations" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faults in a buck converter" 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_0150

Theory session 45

Source text – *DC-DC Power Conversion* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_dc2dc.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 converter
  → Ćuk converter
  → Flyback converter
  → Forward converter
  → Continuous and discontinuous converter operation
- Complete "Dying battery source" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Instantaneous analyses of DC-DC converter circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Identifying possible root-cause 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_0151

Theory session 46

Source text – *Power Conditioning and Protection* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_psprotect.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 "Battery UPS circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Soft-start time delay" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Component faults in a limited regulator 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.

file wt_0207

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_0196

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**
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.

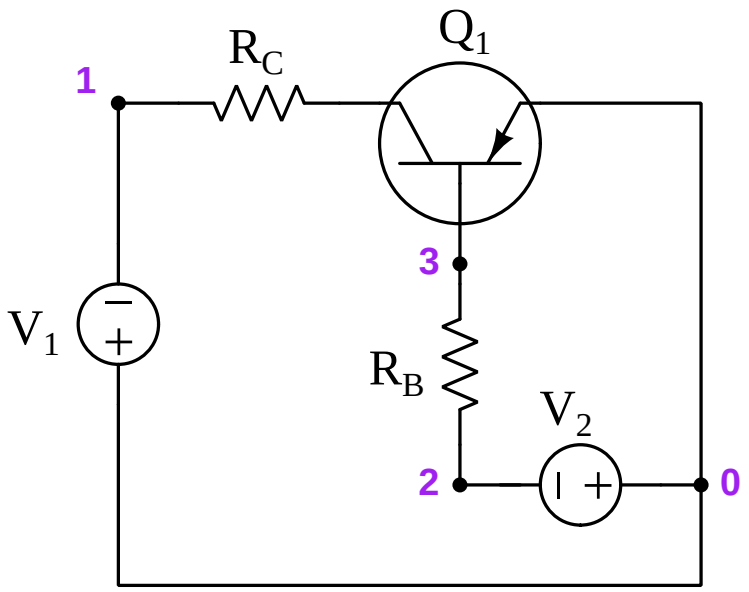
`Grading`

◯ [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, including the β value of Q_1)



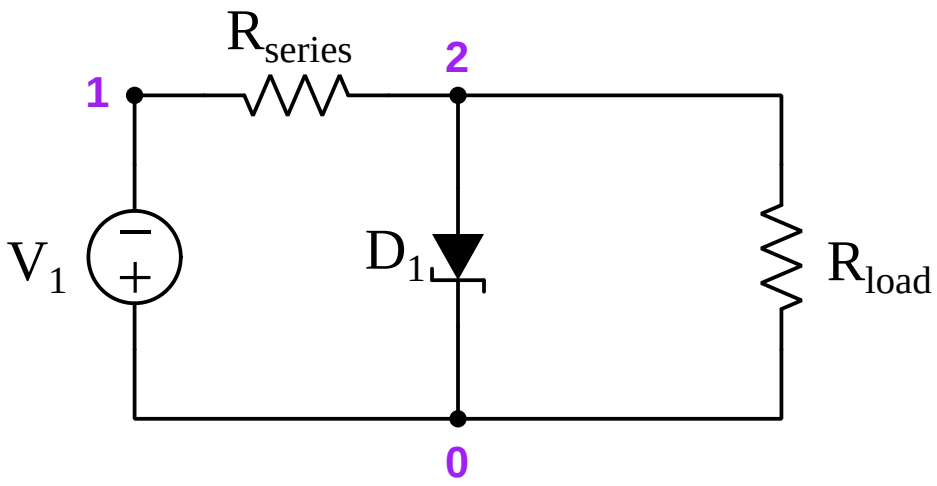
`Grading`

- ◯ [20%] Current magnitude and direction through resistor R_C (I_{RC})
- ◯ [20%] Current magnitude and direction through node 3 (I_3)
- ◯ [20%] All current magnitudes and directions entering and exiting node 0
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ◯ [20%] Voltage magnitude and polarity across resistor R_B (V_{RB})

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

Problem #3

(Component values randomly chosen by instructor, including Zener breakdown voltage rating of D_1)



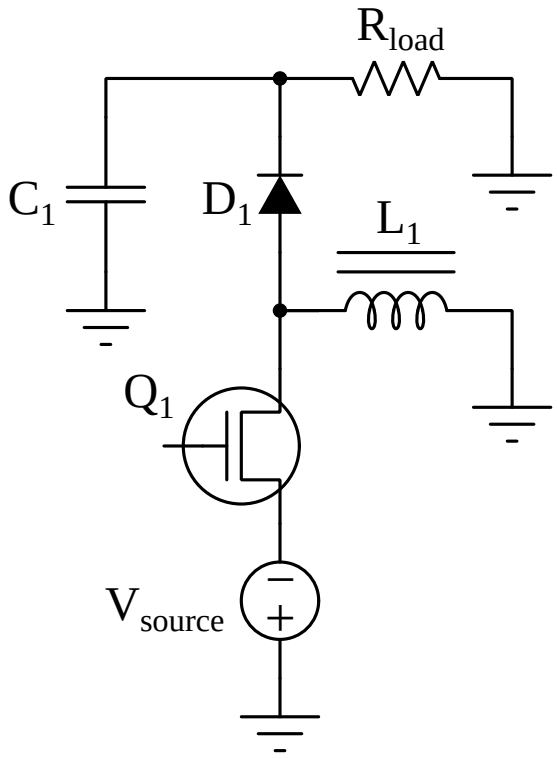
Note: the instructor will choose component values simple enough that you will not need an electronic calculator to obtain exact solutions. *For this reason, you will not be permitted to use any calculating device when analyzing this circuit!* This prohibition of calculating devices is typical during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

`Grading`

- ◯ [20%] Current magnitude and direction through diode D_1 (I_{D1})
- ◯ [20%] Current magnitude and direction through node 1 (I_1)
- ◯ [20%] All current magnitudes and directions entering and exiting node 2
- ◯ [20%] Voltage magnitude and polarity between nodes 1 and 2 (V_{1-2})
- ◯ [20%] Voltage magnitude and polarity across resistor R_{load} (V_{load})

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

Problem #4

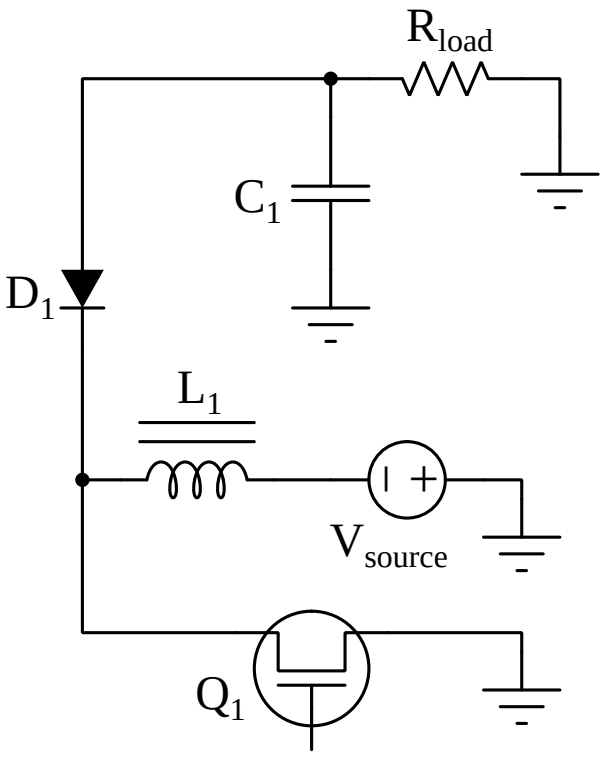


`Grading`

- ◯ [20%] All current directions when transistor is in the "on" state
- ◯ [20%] All voltage polarities when transistor is in the "on" state
- ◯ [20%] All current directions when transistor is in the "off" state
- ◯ [20%] All voltage polarities when transistor is in the "off" state
- ◯ [20%] Energy efficiency if V_{source} = _____, I_{source} = _____, V_{load} = _____, and I_{load} = _____

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

Problem #5

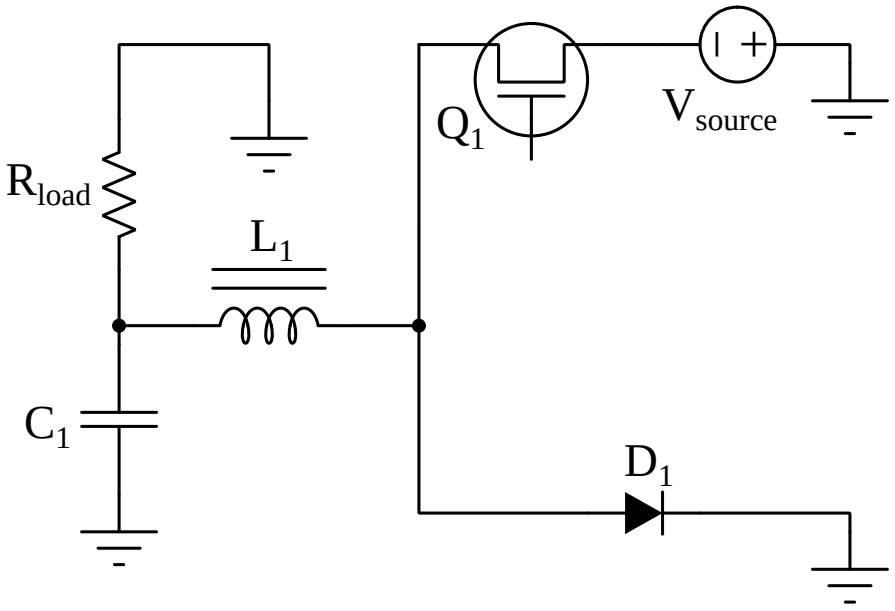


`Grading`

- ◯ [20%] All current directions when transistor is in the "on" state
- ◯ [20%] All voltage polarities when transistor is in the "on" state
- ◯ [20%] All current directions when transistor is in the "off" state
- ◯ [20%] All voltage polarities when transistor is in the "off" state
- ◯ [20%] I_{load} if V_{source} = _____, I_{source} = _____, V_{load} = _____, and Efficiency = _____

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

Problem #6



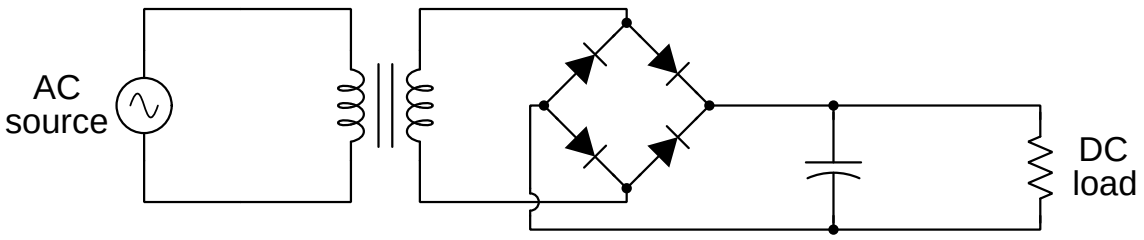
`Grading`

- ◯ [20%] All current directions when transistor is in the "on" state
- ◯ [20%] All voltage polarities when transistor is in the "on" state
- ◯ [20%] All current directions when transistor is in the "off" state
- ◯ [20%] All voltage polarities when transistor is in the "off" state
- ◯ [20%] Energy efficiency if V_{source} = _____, I_{source} = _____, V_{load} = _____, and I_{load} = _____

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

Problem #7

(Component values randomly chosen by instructor, including the turns of each transformer winding)



`Grading`

- ◯ [20%] Current directions through rectifier network during one half-cycle of the AC source
- ◯ [20%] Current directions through rectifier network during other half-cycle of the AC source
- ◯ [20%] Peak voltage magnitude across load (V_{load} pk)
- ◯ [20%] Energy stored in capacitor at its peak voltage (E_C)
- ◯ [20%] RMS voltage magnitude at transformer secondary winding (V_{sec})

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) Predict voltages, currents, and/or frequencies in a single- or three-phase AC-DC rectifier circuit.
  Ohm's Law, Kirchhoff's Voltage Law, diode behavior, rectifier circuit behavior, RMS versus peak AC quantities, properties of wye-connected networks, properties of delta-connected networks

- (Question #2) 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 #3) 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 #4) Calculate temperatures, voltages, currents, and/or power dissipations for a power semiconductor component heat sink given all the necessary parameters.
  Thermal resistance, Joule's Law

- (Question #5) Determine voltages and currents for a switching power-conversion circuit.
  Behavior of sources vs. loads, capacitor behavior, inductor behavior, BJT behavior, FET behavior, diode behavior, KVL, KCL, efficiency

- (Question #6) Determine possible faults in a semiconductor power control circuit.
  Effects of opens vs. shorts, BJT behavior, FET behavior, thyristor behavior, rectifier circuits, PWM power control, switch-mode DC-DC power converters, DC-AC power converters

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

- (Question #8 – REVIEW) Calculate and graph voltages, currents, and/or stored energy values over time for a resistor-inductor circuit.
  Properties of series and parallel networks, behaviors of sources and loads, inductor behavior, inverse exponential calculations, conservation of energy, Kirchhoff's Voltage Law, inductor energy calculation, graph sketching

- (Question #9 – REVIEW) Calculate voltages, currents, and/or powers in a transformer circuit
  Transformer behavior, Ohm's Law, Joule's Law

file wt_0088

Theory session 49

Source text – *Combinational Logic* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_comblogic.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 "Boolean expressions from gate circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Boolean expressions from relay circuits" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Circuits from three-input truth tables" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Timing diagrams for gate circuits" in the Quantitative Reasoning section of the Questions chapter.

Discuss as a group your learning experience studying combinational logic 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.
- `tshoot` circuit troubleshooting simulation software in the "no-fault" mode (`tshoot -nofault`), particularly circuit_009.

  file wt_0244

Theory session 50

Source text – *Encoders and Decoders* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_encoder.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 "74HC147 encoder" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Integer conversion table" in the Quantitative Reasoning section of the Questions chapter.
- Complete "5-line to 32-line decoder" 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_0032

Theory session 51

Source text – *Multiplexers and Demultiplexers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_mux.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 "74HC151 mux" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Arbitrary SOP expression" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Faulted concentrator 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.

file wt_0033

Theory session 52

Source text – *Latching Logic* learning module

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

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

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Read, reflect, and update your Theory Journal on the Digital pulse criteria section of the Derivations and Technical References chapter.
  - → Show how to measure propagation delay in at least one of the oscillographs shown
  - → Show how to measure rise or fall time in at least one of the oscillographs shown
  - → Show how to measure set-up time in at least one of the oscillographs shown
  - → Show how to measure hold time in at least one of the oscillographs shown
- Update your "Conceptual Toolbox" and cite foundational concepts from it applicable to today's reading and problem-solving.
- Work through the operation of some of the latch and flip-flop examples shown in the Case Tutorial chapter:
  - → Copy-and-paste just the schematic diagram and given input conditions to a graphic editor program, and then use that program to sketch your own output signals, checking afterward to see if your answers agree with those shown in the module
  - → Make up new input signals of your own and predict what the output response(s) will be to those
- Complete "Sound-controlled lamp" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many timing diagrams shown in this Tutorial, which may be new to the reader as a means of documenting the behavior of digital logic circuits, and therefore may cause some confusion. Here are some proven strategies for success:

- Closely examine each of the example circuits shown in the text, on your own, until you can successfully predict those circuits' outputs based on the input states shown in each timing diagram. Cover up the output signals shown, then uncover them to check your work for correctness. *Unless and until you can do the problem(s) on your own, you have not yet mastered the operation of these latching 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_0034

Theory session 53

Source text – *Shift Registers* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_shiftreg.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.
- Locate a shift register IC datasheet containing an example timing diagram (for example, from the `Datasheets/logic` directory of your EETREF document collection) and explain how the output states shown in that diagram are caused by the given input conditions.
- Complete "Frequency divider design" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Sequential tail-light blinker" in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many timing diagrams shown in this Tutorial, which may be new to the reader as a means of documenting the behavior of digital logic circuits, and therefore may cause some confusion. Here are some proven strategies for success:

- Closely examine each of the example circuits shown in the text, on your own, until you can successfully predict those circuits' outputs based on the input states shown in each timing diagram. Cover up the output signals shown, then uncover them to check your work for correctness. *Unless and until you can do the problem(s) on your own, you have not yet mastered the operation of these shift register 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_0035

Theory session 54

Source text – *Digital Counters* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_counter.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.
- Locate a counter IC datasheet containing an example timing diagram (for example, from the `Datasheets/logic` directory of your EETREF document collection) and explain how the output states shown in that diagram are caused by the given input conditions.
- Complete "Counter circuit identification" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Frequency division" in the Quantitative Reasoning section of the Questions chapter.

NOTE: there are many timing diagrams shown in this Tutorial, which may be new to the reader as a means of documenting the behavior of digital logic circuits, and therefore may cause some confusion. Here are some proven strategies for success:

- Closely examine each of the example circuits shown in the text, on your own, until you can successfully predict those circuits' outputs based on the input states shown in each timing diagram. Cover up the output signals shown, then uncover them to check your work for correctness. *Unless and until you can do the problem(s) on your own, you have not yet mastered the operation of these counter 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_0036

Theory session 55

Source text – *PLC Counter Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_counter.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 "Determining bit statuses from switch conditions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining necessary switch conditions for bit statuses" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Motor start-up limit counter" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs implementing different types of *counter* instructions.
- Time permitting during the class session, experiment with creating and running a PLC program either in simulation software or in a real PLC implementing a *shift register* instruction.

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:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0265

Theory session 56

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.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 "Determining color highlighting from switch conditions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining bit statuses from color highlighting" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sequenced-start conveyor belts" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs implementing different types of *timer* instructions.

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:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0266

Theory session 57

Source text – *Digital Signal Integrity* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_integrity.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.
- Examine and reflect on the Oscilloscope, cable, and signal generator section of the Case Tutorial chapter, and answer the following questions:
  → Identify all waveform imperfections captured in the oscillographs
  → Comment on the effects wrought by each cabling alteration
- Read, reflect, and update your Theory Journal on the Digital pulse criteria section of the Derivations and Technical References chapter.
- Complete "Two crosstalk scenarios" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Pulse waveform oscillographs" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Testing a cable for magnetic crosstalk" 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_0061

Theory session 58

Source text – *Digital Signal Integrity* learning module

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

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

- Examine and reflect on the Demonstration of set-up time section of the Case Tutorial chapter, and answer the following questions:
  - → Explain why the LED could never turn on in the first version of the circuit
  - → Explain why the LED is able to turn on in the second version of the circuit
  - → Identify an alternative strategy for achieving proper set-up time
- Read, reflect, and update your Theory Journal on the Latch-up in integrated circuits section of the Derivations and Technical References chapter.
- Complete "The Soul of a New Machine" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Simultaneous crosstalk" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Measuring jitter using an eye diagram" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Evaluating set-up and hold times" 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_0061

Theory session 59

Oral Presentations

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

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

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

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

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

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

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

file wt_0248

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**
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

Write a Boolean expression and sketch both a logic gate and a relay ladder-logic circuit diagram to implement the following truth table:

A	B	C	Output
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

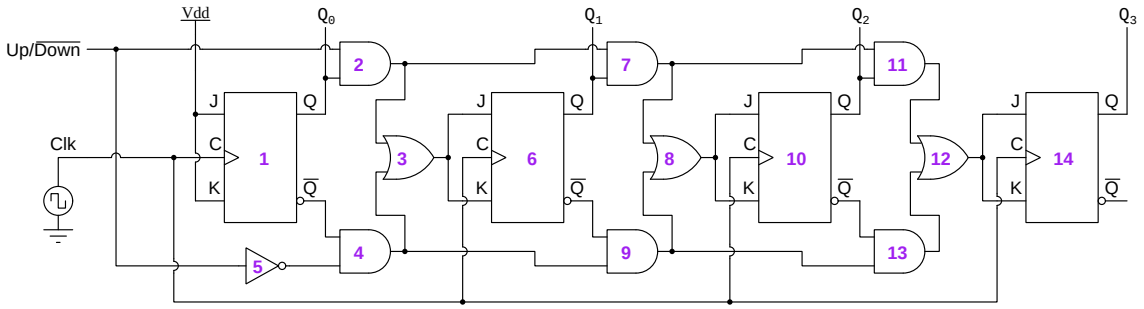
`Grading`

- ◯ [20%] Boolean expression matches truth table
- ◯ [20%] Logic gate diagram implements Boolean expression
- ◯ [20%] Relay ladder logic diagram implements Boolean expression
- ◯ [20%] Effect on truth table if _____ fails (*high*/*low*) in the gate circuit
- ◯ [20%] Effect on truth table if _____ fails (*open*/*shorted*) in the relay circuit

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

Problem #3

Sketch a timing diagram showing the output states of this circuit given an initial count value of ____ and the Up/Down control line in the (*high*/*low*) state, for eight cycles of the clock pulse:



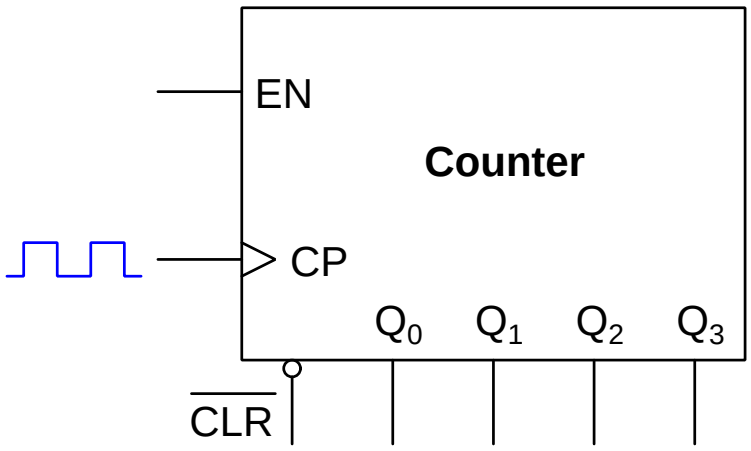
`Grading`

- ◯ [20%] Output states for the first four clock pulses
- ◯ [20%] Output states for the second four clock pulses
- ◯ [20%] Effect on count sequence if _____ fails with (*high*/*low*) output
- ◯ [20%] Effect on count sequence if _____ fails with (*high*/*low*) output
- ◯ [20%] Identify if this is a synchronous or asynchronous counter circuit

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

Problem #4

Complete a schematic diagram for this binary "up" counter so that it counts from zero to ____ and then returns to zero after the *next* clock pulse. The instructor will randomly choose whether this counter has a *synchronous* or *asynchronous* clear input:



`Grading`

- ◯ [20%] Modulus value of the complete counter circuit
- ◯ [20%] Complete count sequence starting from a value of ____
- ◯ [20%] Additional circuitry correct for truncating the count sequence
- ◯ [20%] Enable input (EN) properly connected to allow counting
- ◯ [20%] Clear signal frequency if clock frequency is ____ Hz

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

Problem #5

Sketch a DC motor start/stop control circuit using an SR latch and two pushbutton switches (instructor will choose either *NO* or *NC*), with a transistor interposing between the latch IC and the high-current motor. Assume the use of a CMOS latch IC.

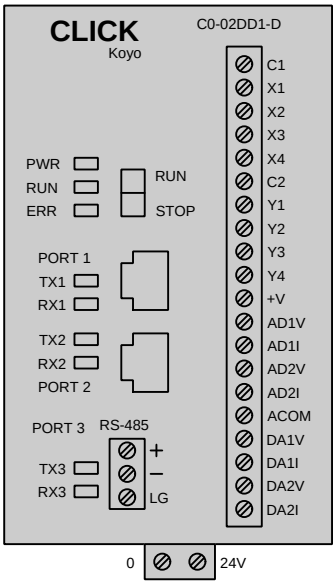
Grading

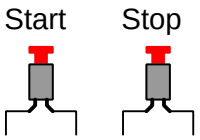
- ◯ [20%] SR latch never enters the "invalid" state with just one pushbutton pressed at any time
- ◯ [20%] Pressing "Start" switch sets the latch and pressing "Stop" switch resets the latch
- ◯ [20%] Proper pullup/pulldown resistors
- ◯ [20%] Correct driving signal to power transistor
- ◯ [20%] Correct controlled current direction for power transistor

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

Problem #6

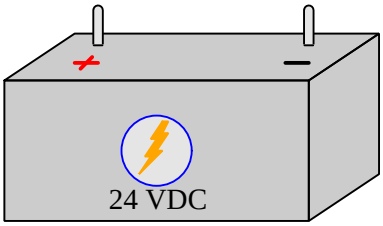
Sketch a ladder diagram (LD) program for this Koyo CLICK PLC to control the starting and stopping of an electric motor, as well as the wires necessary to connect the PLC to start and stop switches and a transistor to switch DC power to the motor so that the PLC's output channel does not have to conduct more than a few milliAmperes of current at the most. Note the part number of this PLC, which will be important for your circuit design! You are welcome to reference the datasheet for this particular PLC during your problem-solving time. Feel free to add components if needed:





Power BJT

Motor



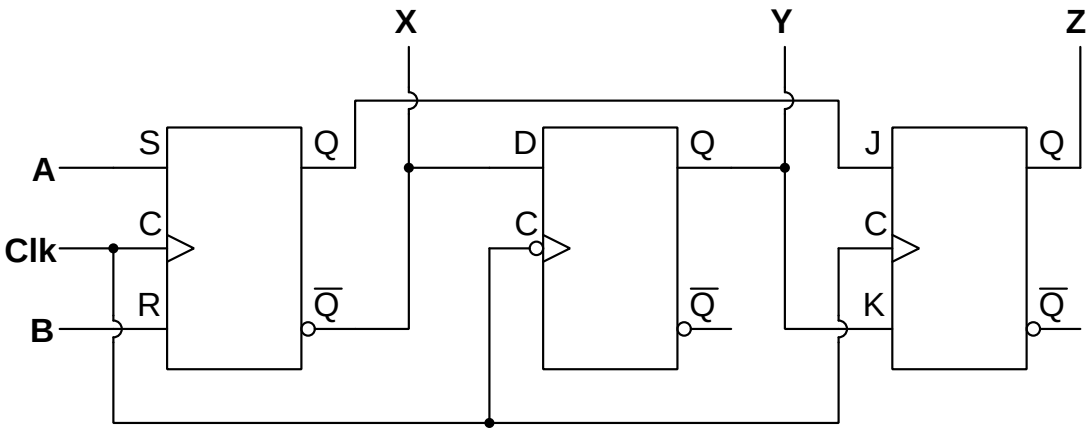
`Grading`

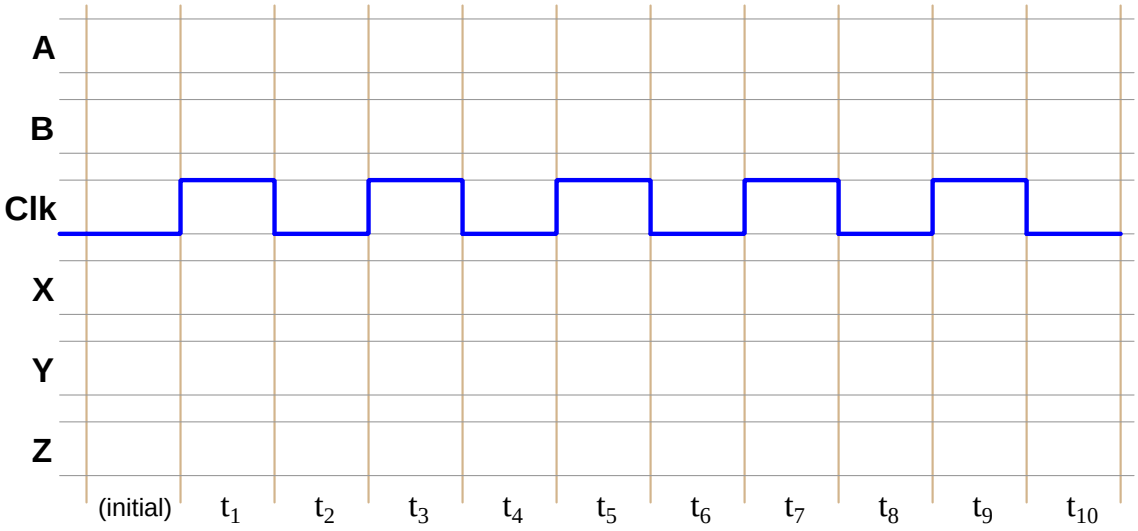
- ◯ [10%] Proper wiring between Start switch and the PLC's input channel ____
- ◯ [10%] Proper wiring between Stop switch and the PLC's input channel ____
- ◯ [10%] Proper wiring between PLC and transistor (NOTE: you may choose either NPN or PNP as you see fit!)
- ◯ [10%] Proper wiring between motor and transistor
- ◯ [10%] Proper wiring to power the PLC processor itself
- ◯ [20%] Program activates output Y3 when "Start" input energized
- ◯ [20%] Program de-activates output Y3 when "Stop" input energized
- ◯ [10%] Program latches output Y3 in its last state when both switches unpressed

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

Problem #7

Complete a timing diagram for this circuit (instructor sketches all output states during the "initial" period, as well as the A and B input pulse waveforms in their entireties):





`Grading`

◯ [10% per time period] All output states correct

Note: full credit given only for answers that are correct <u>and</u> 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) Determine logic states within a combinational logic circuit.
  Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts

- (Question #2) Sketch a latch or flip-flop circuit to fulfill a specified function.
  A SOLID understanding of all latch and flip-flop types and their behaviors, timing diagrams, pull-up and pull-down resistor function, BJT and MOSFET switching circuits, thyristors, optoisolators

- (Question #3) Evaluate digital timing diagrams for adequate signal integrity.
  Timing diagrams, AC quantities, switch bounce, oscilloscope display interpretation, eye diagram interpretation, resonance, propagation delay, set-up time, hold time, logic levels in TTL and CMOS circuits

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

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

file wt_0247