

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

NAME: \_\_\_\_\_

Last update 4 March 2024

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

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

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

NAME: \_\_\_\_\_

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

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

**Essential information about this course:**

- Learning to independently digest technical information and solve novel problems is even more important than learning electrical and electronic theory. To develop these skills we will *read* extensively to learn general principles, then tackle unfamiliar problems by logically applying those principles.
- This is a theory course, *but it is not lecture-based*. Pre-class reading assignments replace lecture, while class time is spent discussing the text and solving related problems.
- Thorough preparation for and full participation in every theory session are minimum expectations. Lack of preparation will result in point deductions, as will lack of participation and/or late arrival.
- Half of your course grade comes from “oral presentations” where you solve problems in full view of classmates and instructor just like during a technical job interview.
- Half of your course grade comes from written “mastery exams” where every question must be correctly answered to pass. Multiple re-tries are allowed on different exam versions, but only the first exam’s score counts toward your course grade.
- You should budget a minimum of 12 hours per week for this course, approximately 4 hours in-class and 8 hours out-of-class preparation.
- Successful students (1) prioritize their study time, (2) test themselves on upcoming oral presentation and written exam topics, (3) and master principles before memorizing procedures.

## Values

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

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

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

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

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

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

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

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

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

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

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

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

## EET Program Learning Outcomes

- (1) **COMMUNICATION and TEAMWORK** – Accurately communicate ideas across a variety of media (oral, written, graphical) to both technical and non-technical audiences; Function effectively as a member of a technical team.
- (2) **SELF-MANAGEMENT** – Arrive on time and prepared; Work diligently until the job is done; Budget resources appropriately to achieve objectives.
- (3) **SAFE WORK HABITS** – Comply with relevant national, state, local, and college safety regulations when designing, prototyping, building, and testing systems.
- (4) **ANALYSIS and DIAGNOSIS** – Select and apply appropriate principles and techniques for both qualitative and quantitative circuit analysis; Devise and execute appropriate tests to evaluate electronic system performance; Identify root causes of electronic system malfunctions.
- (5) **PROBLEM-SOLVING** – Devise and implement solutions for technical problems appropriate to the discipline.
- (6) **DOCUMENTATION** – Interpret and create technical documents (e.g. electronic schematic diagrams, block diagrams, graphs, reports) relevant to the discipline.
- (7) **INDEPENDENT LEARNING** – Select and research information sources to learn new principles, technologies, and/or techniques.

## Course description

This course reviews DC and AC circuit theory while introducing principles of C-language computer programming, then builds on that foundation to explore analog amplifier circuits (both discrete-transistor and operational amplifier), principles of RF and radio systems, operational amplifier circuits, AC motor controls, and protective relaying. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

## Course learning outcomes

- Predict the performance of resistor networks, time-delay networks, AC reactive networks, transistor amplifiers, simple RF circuits, operational amplifier circuits, and AC power control circuits given schematic diagrams, component values, and other circuit parameters. (Addresses Program Learning Outcomes 4, 6)
- Compute component values necessary to achieve stated performance goals in resistor networks, transistor amplifier circuits, RF communication circuits, operational amplifier circuits, and AC power control circuits. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple filter networks, transistor amplifier circuits, operational amplifier circuits, and AC power control circuits to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to fundamental DC/AC circuit theory, analog electronics, RF systems, and AC power circuits as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in resistor networks, transistor amplifier circuits, radio transceiver systems, operational amplifier circuits, and AC power control circuits given schematic diagrams and reported symptoms. (Addresses Program Learning Outcomes 5, 6)

## 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)

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

## Required Tools, Supplies, and Software

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

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

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

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

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

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

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

## Required Tools, Supplies, and Software

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

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

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

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

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

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

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

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

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

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

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

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

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

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## Grading standards for Theory courses

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

- Oral presentation scores = 50%
- Written exam scores = 50% (Note: all exams are mastery-based, which means they must be eventually passed with correct answers for every question in order to pass the course)
- Unpreparedness for theory sessions =  $-1\%$  per session
- Non-participation for theory sessions =  $-1\%$  per session

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

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

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

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

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

A failing (F) grade will be earned for the entire course if any written exam is not passed (i.e. *all* answers correct) on or before the deadline date, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another’s work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

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## Theory session 01

**Source text** – *Career Guide* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_career.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf)

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

- Read, outline, and reflect on the “Interviews and the Screening Process” chapter of the *Career Guide* document
- Research open positions on job search engines (e.g. [Indeed.com](https://www.indeed.com)) searching for job titles listed in the “What is Electronics” chapter, focusing on those jobs listing a two-year (Associate’s) degree in electrical or electronics technology for education

Complete the following *during* the scheduled session:

- Discuss what you read in the *Career Guide*
  - Share your answers for selected “Sample Technical Questions”
  - Share your answers for selected “Sample Behavioral Questions”
- Discuss what you found in your job search:
  - What technical skills are common to these jobs?
  - What non-technical skills are common to these jobs?
- Discuss time and effort necessary to succeed in this program:
  - Full load = 12 credits = 36 hours/week total time commitment + *General Education courses!*
  - Make *daily contact* with instructor, even if absent
  - Exert *honest effort* to solve every problem before asking for help
  - *Self-start* when faced with challenges and take ownership of your education
  - Never *procrastinate*, as this guarantees failure
- [Optional] – sign FERPA release forms

**Forms provided by the instructor for today’s session:**

- FERPA release form
- IETTI-222 Theory course document (printed from cover page through Theory Session 2)
- IETTI-221 Experiments course document (only if you are enrolled in this course as well)
- IETTI-220 Projects course document (only if you are enrolled in this course as well)

**Important resources:**

- <https://ibiblio.org/kuphaldt/socratic/model>, the *Modular Electronics Learning Project* web page containing all course documents, tutorials, and problem sets you will need in these courses
  - <https://ibiblio.org/kuphaldt/socratic/model/index#courses>, links to all IETTI course documents
- <https://ibiblio.org/kuphaldt/socratic/model/calendar.html>, our semester calendar showing dates for theory sessions, special events, and all-lab project sessions
- [https://ibiblio.org/kuphaldt/socratic/model/daily\\_schedule.pdf](https://ibiblio.org/kuphaldt/socratic/model/daily_schedule.pdf), showing Monday-Friday class schedule
- “Required Tools, Supplies, and Software” page (in this document)
- EETREF – a collection of digital documents often referenced in homework assignments, stored as a folder on the Desktop of every computer in the lab

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## Theory session 02

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - What is a programming language?
  - Creating and running a simple C program
  - C program fundamentals
  - Writing neat code
  - Comments
- Complete “Writing your first C program” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Re-writing a ‘Hello world!’ program” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Find mistakes in a very simple program” in the Diagnostic Reasoning section of the Questions chapter.

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

### Theory Session Expectations:

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

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

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## Theory session 03

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Formatted output using printf
  - Data types
  - Basic mathematical functions
  - Using the C math library
- Explain the following foundational concepts for DC circuits:
  - Ohm's and Joule's Laws
  - Kirchhoff's Voltage and Current Laws
  - Properties of series networks
  - Properties of parallel networks
  - The distinction between an electrical *source* and an electrical *load*
- Complete "Using C to analyze a series resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze a parallel resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Using C to analyze a series-parallel resistor circuit" in the Quantitative Reasoning section of the Questions chapter.
- Identify specific modules in the Modular Electronics Learning Project collection with tutorials and practice problems to refresh your knowledge of the DC circuit concepts you find most challenging.

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

### Theory Session Expectations:

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

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

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## Theory session 04

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Read, outline, and reflect on the following section of the Tutorial chapter:  
→ Formatted input using scanf
- Complete “Using C to analyze a multi-source circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Find mistakes in a millimeter conversion program” in the Diagnostic Reasoning section of the Questions chapter.

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

### Theory Session Expectations:

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

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

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## Theory session 05

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Explain the following foundational concepts for AC circuits:
  - Peak versus RMS quantities
  - Resistance versus reactance versus impedance
  - Phasor diagram
  - Power factor
  - Polyphase AC power
- Complete “Using C to analyze a series AC RLC circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Using C to analyze a parallel AC RLC circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Case-sensitivity in variable names” in the Diagnostic Reasoning section of the Questions chapter.
- Identify specific modules in the Modular Electronics Learning Project collection with tutorials and practice problems to refresh your knowledge of the AC circuit concepts you find most challenging.

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

### Theory Session Expectations:

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

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

file wt\_0221

## Theory session 06

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

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

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

If time permits during the theory session, watch a video demonstration of **Sonic Pi** which is an application allowing you to create music using coding (in the Ruby language). A good example is Dylan Beattie’s presentation “The Art of Code” during the 27-31 January 2020 NDC Conference, available on YouTube.

### Theory Session Expectations:

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

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

file wt\_0222

## Theory session 07

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Complete “RC time-constant calculator program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Using C to analyze an RC charging-discharging circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Writing an LR time-delay analysis program” in the Quantitative Reasoning section of the Questions chapter.
- Identify specific modules in the Modular Electronics Learning Project collection with tutorials and practice problems to refresh your knowledge of capacitor and inductor time-delay circuits.

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

### Theory Session Expectations:

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

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

file wt\_0223



## Theory session 08

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

- Complete “Using C to analyze a series AC resistor-capacitor circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Writing a cutoff frequency calculator program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Writing a low-pass filter simulation program” in the Quantitative Reasoning section of the Questions chapter.

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

### Theory Session Expectations:

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

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

file wt\_0224

## Theory session 09

**Source text** – *Texas Instruments MSP430 Microcontrollers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_mcu\\_430.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_mcu_430.pdf)

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

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

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

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

### Theory Session Expectations:

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

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

file wt\_0225

## Theory session 10

**Source text** – *Texas Instruments MSP430 Microcontrollers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_mcu\\_430.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_mcu_430.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0226

### Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. You are allowed to bring notes for reference, but not allowed to read them to your audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

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

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

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

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

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

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

## Foundational Concepts

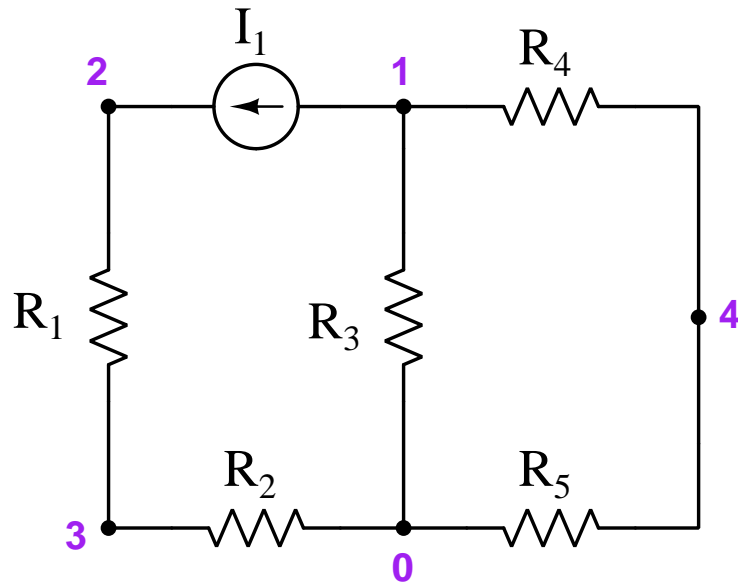
The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	$R$ vs. $X$ vs. $Z$
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's Voltage Law	
Kirchhoff's Current Law	
Electric fields and capacitance	
Magnetic fields and inductance	
Inverse-exponential growth/decay	

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

**Problem #1**

(Component values randomly chosen by instructor):



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

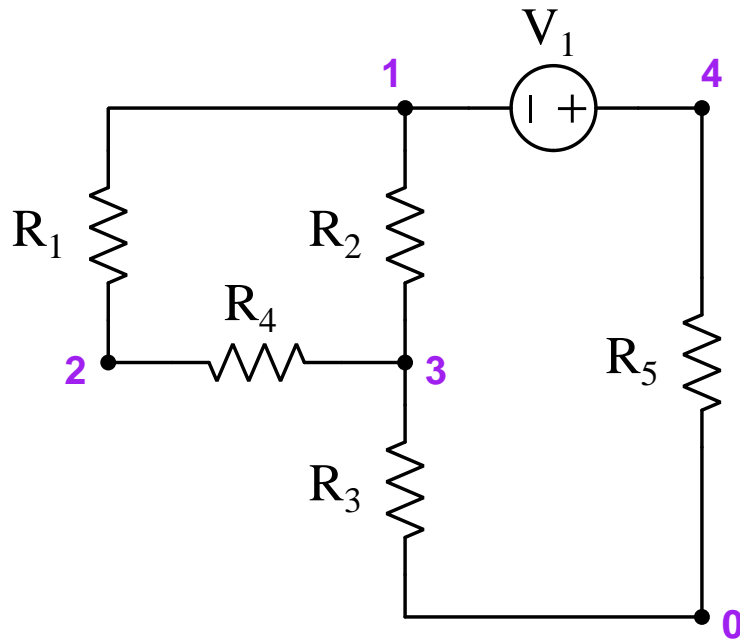
**Grading**

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

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

**Problem #2**

(Component values randomly chosen by instructor):



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

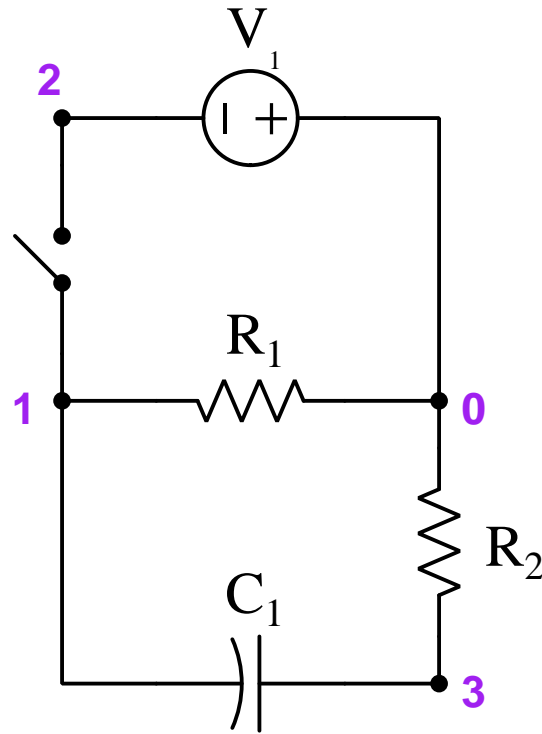
**Grading**

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

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

### Problem #3

Assume the switch has been in the (*open/closed*) state long enough for the capacitor's voltage to stabilize, and is suddenly toggled to the opposite state at time  $t = 0$ . All component values will be randomly chosen by instructor, as well as the point in time ( $t = \underline{\hspace{1cm}}$ ) at which all values will be calculated:



### Grading

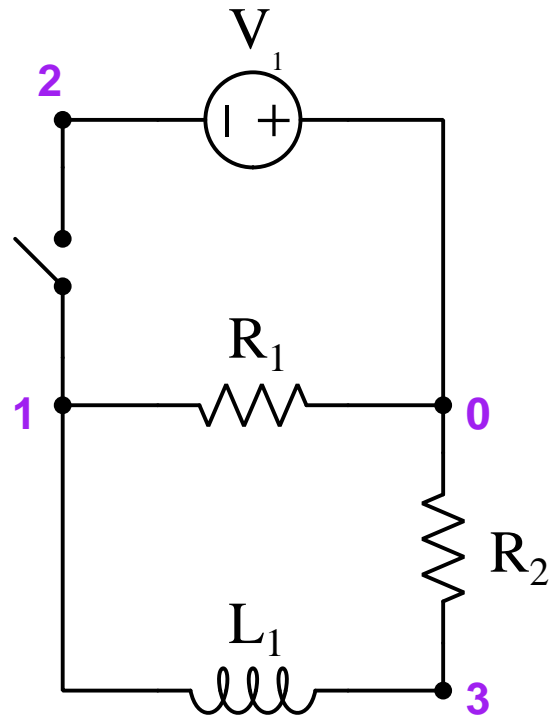
- ☐ [20%] Current magnitude and direction through resistor  $R_2$  ( $I_{R2}$ )
- ☐ [20%] Current magnitude and direction through node 2 ( $I_2$ )
- ☐ [20%] Current magnitude and direction through capacitor  $C_1$  ( $I_{C1}$ )
- ☐ [20%] Voltage magnitude and polarity across capacitor  $C_1$  ( $V_{C1}$ )
- ☐ [20%] Voltage magnitude and polarity across resistor  $R_1$  ( $V_{R1}$ )

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



**Problem #4**

Assume the switch has been in the (*open/closed*) state long enough for the inductor's current to stabilize, and is suddenly toggled to the opposite state at time  $t = 0$ . All component values will be randomly chosen by instructor, as well as the point in time ( $t = \underline{\hspace{1cm}}$ ) at which all values will be calculated:

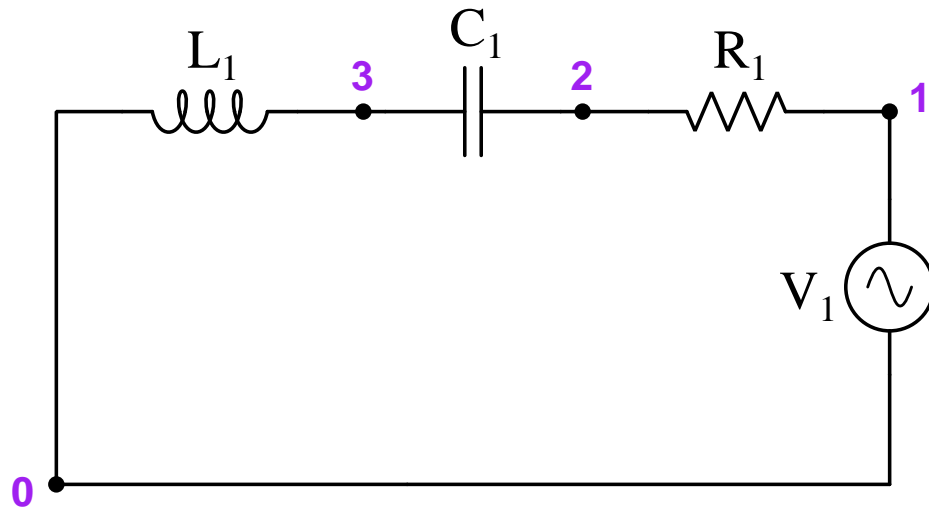
**Grading**

- ☐ [20%] Current magnitude and direction through resistor  $R_2$  ( $I_{R2}$ )
- ☐ [20%] Current magnitude and direction through node 2 ( $I_2$ )
- ☐ [20%] Current magnitude and direction through inductor  $L_1$  ( $I_{L1}$ )
- ☐ [20%] Voltage magnitude and polarity across inductor  $L_1$  ( $V_{L1}$ )
- ☐ [20%] Voltage magnitude and polarity across resistor  $R_1$  ( $V_{R1}$ )

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

**Problem #5**

(Component values randomly chosen by instructor):

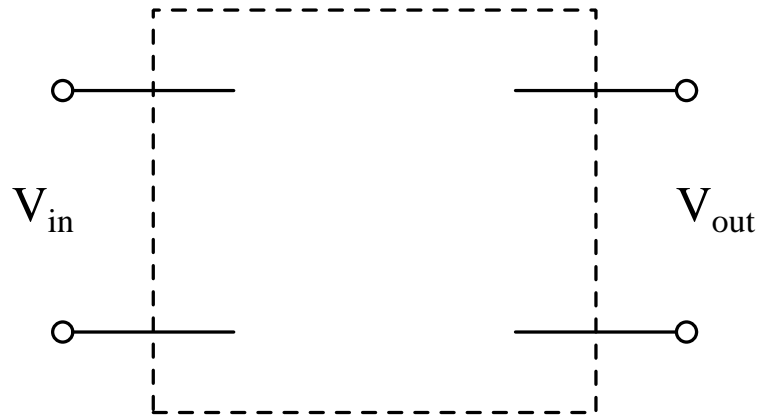
**Grading**

- ☐ [20%] 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 #6**

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



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

**Grading**

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

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

### Problem #7

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

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

### Grading

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

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

## Theory session 12

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

- (Question #1) Calculate voltage, current, resistance, and/or power in a series DC resistor circuit.  
*Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks*
- (Question #2) Calculate voltage, current, resistance, and/or power in a parallel DC resistor circuit.  
*Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of parallel networks*
- (Question #3) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel DC resistor circuit.  
*Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks*
- (Question #4) Calculate voltages, currents, and/or times for a resistor-capacitor circuit.  
*Properties of series and parallel networks, behaviors of sources and loads, capacitor behavior, inverse exponential calculations*
- (Question #5) Calculate voltages, currents, and/or times for a resistor-inductor circuit.  
*Properties of series and parallel networks, behaviors of sources and loads, inductor behavior, inverse exponential calculations*
- (Question #6) Design and sketch a passive filter circuit with a specified cutoff frequency and characteristic.  
*Filter circuit behavior, capacitive reactance, inductive reactance, resonance*
- (Question #7) Calculate voltage, current, and/or impedance in a series or parallel AC network.  
*Capacitive reactance, inductive reactance, impedance, complex-number arithmetic, properties of series networks, properties of parallel networks, Ohm's Law, Kirchhoff's Laws*
- (Question #8) Convert between different forms of digital numeration (e.g. binary, octal, hexadecimal, decimal).  
*Signed binary integers, unsigned binary integers, octal notation, hexadecimal notation*
- (Question #9) Determine logic states within a combinational logic circuit.  
*Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts*

## Theory session 13

**Source text** – *Printed Circuit Boards* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_pcb.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_pcb.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0278

## Theory session 14

**Source text** – *Transistor switching circuits* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_qswitch.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_qswitch.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Transistor summary” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Proper BJT types” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Explaining the meaning of calculations” in the Conceptual Reasoning section of the Questions chapter.
- Complete “BJT switching circuit simulation program” in the Quantitative Reasoning section of the Questions chapter.

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

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

### Theory Session Expectations:

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

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

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## Theory session 15

**Source text** – *Transistor Biasing* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_qbias.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_qbias.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Another BJT with slow-changing DC input” in the Conceptual Reasoning section of the Questions chapter.
- Complete “BJT amplifier biasing strategies” in the Conceptual Reasoning section of the Questions chapter.
- Complete “DC signal sweep simulation program” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0039



## Theory session 16

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_bjtamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_bjtamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Amplifier fundamentals
  - BJT amplifier configurations
  - Common-collector amplifier
  - Common-emitter amplifier
- Complete “Altering common-emitter resistor values” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Common-emitter calculations” in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – if time permits, write a computer program in a text-based language simulating the “Common-emitter calculations” circuit example.

### Theory Session Expectations:

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

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

### Additional resources:

- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!  
file wt\_0040

## Theory session 17

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_thevenin\\_norton.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_thevenin_norton.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Examine and reflect on the following sections of the Case Tutorial chapter, identifying which foundational concepts (e.g. Ohm's Law, Kirchhoff's Laws, etc.) were applied to calculate the values shown:
  - Example: Thévenizing a multi-source network
  - Example: Nortonizing a multi-source network
- Complete “Thévenizing a loaded voltage divider” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Fault current of a battery bank” in the Diagnostic Reasoning section of the Questions chapter.
- **Coding challenge** – if time permits, write a computer program in a text-based language simulating any of the questions answered today or any of the example circuits shown in the Tutorial.

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

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

### Theory Session Expectations:

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

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

### Additional resources:

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

file wt\_0230

## Theory session 18

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_bjtamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_bjtamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Common-base amplifier
  - Amplifier gain comparisons
  - Input and output impedances
- Complete “Achieving a specified voltage gain” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Common-emitter quiescent simulation program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faulty audio amplifier design” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!  
file wt\_0041

## Theory session 19

**Source text** – *Multi-Transistor Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_multiamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_multiamp.pdf)

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

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

### Theory Session Expectations:

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

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

### Additional resources:

- Animation of class-B crossover distortion section of the Animations chapter.  
file wt\_0074

## Theory session 20

**Source text** – *Multi-Transistor Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_multiamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_multiamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Differential pairs
  - Current mirrors
  - Active loading
- Complete “Model 324 differential amplifier qualitative analysis” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Audio amplifier quiescent values” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Current mirror calculations” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- Animation of class-B crossover distortion section of the Animations chapter.  
file wt\_0231

## Theory session 21

**Source text** – *Amplifier Performance* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_ampperf.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_ampperf.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0075

## Theory session 22

**Source text** – *Oscillators* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_oscillator.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_oscillator.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Neon lamp relaxation oscillator” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Colpitts oscillator frequency” in the Quantitative Reasoning section of the Questions chapter.
- **Coding challenge** – write a simple computer program in a text-based language to calculate the resonant frequency of an oscillator circuit based on its  $L$  and  $C$  component values.
- Complete “Effects of faults in a strobe light circuit” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

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

file wt\_0056

### Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. You are allowed to bring notes for reference, but not allowed to read them to your audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

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

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

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

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

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

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



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

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

## Foundational Concepts

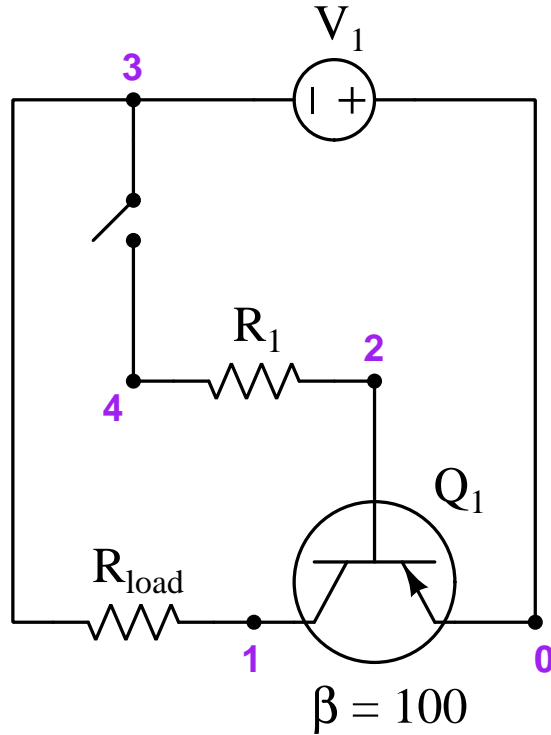
The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

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

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

**Problem #1**

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

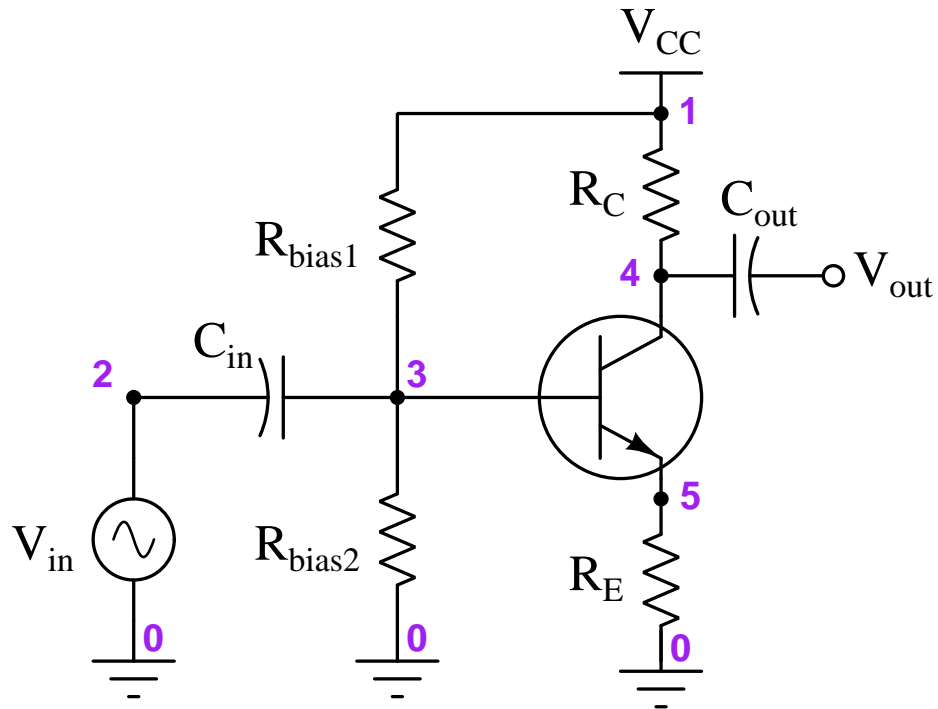
**Grading**

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

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

## Problem #2

(Component values randomly chosen by instructor):



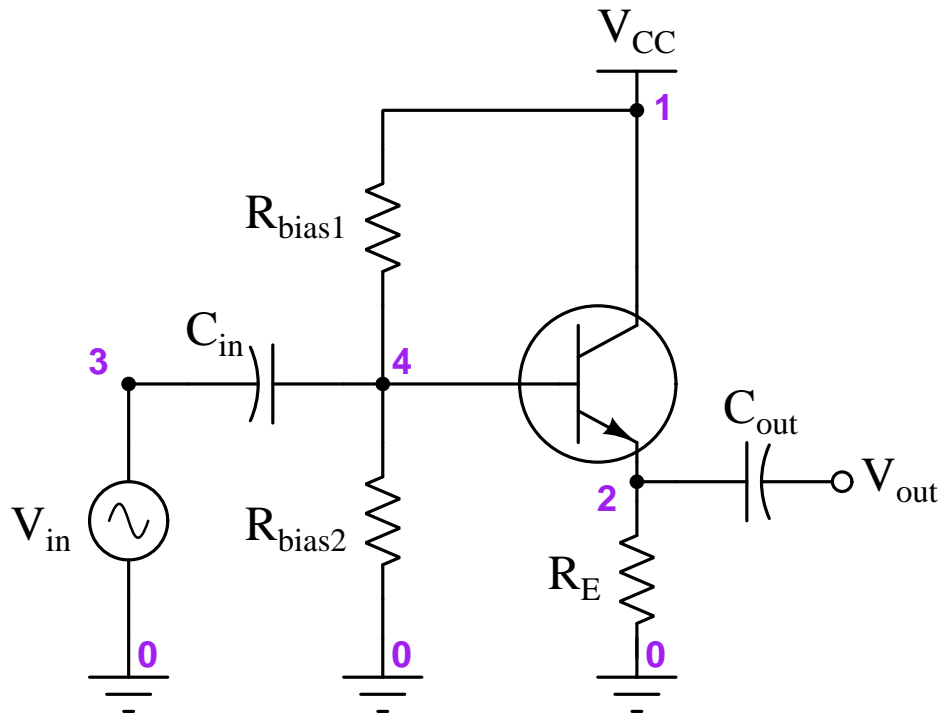
### Grading

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

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

### Problem #3

(Component values randomly chosen by instructor):



#### Grading

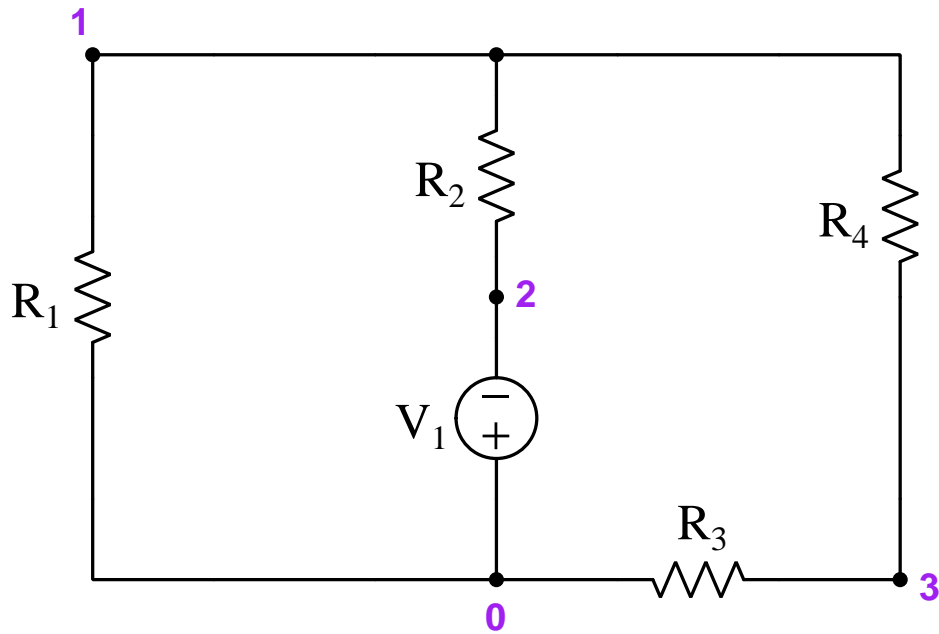
- ☐ [20%] Voltage gain ( $A_V$ ) as a ratio and as a decibel value
- ☐ [20%] Input impedance ( $Z_{in}$ )
- ☐ [20%] Output impedance ( $Z_{out}$ )
- ☐ [20%] Assuming your choice of bias resistor values, specify a DC quiescent voltage  $V_B$  suitable for Class-A operation
- ☐ [20%] Largest AC value of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

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

**Problem #4**

(Component values randomly chosen by instructor):

Thévenize this circuit, assuming resistor \_\_\_\_ is the load:

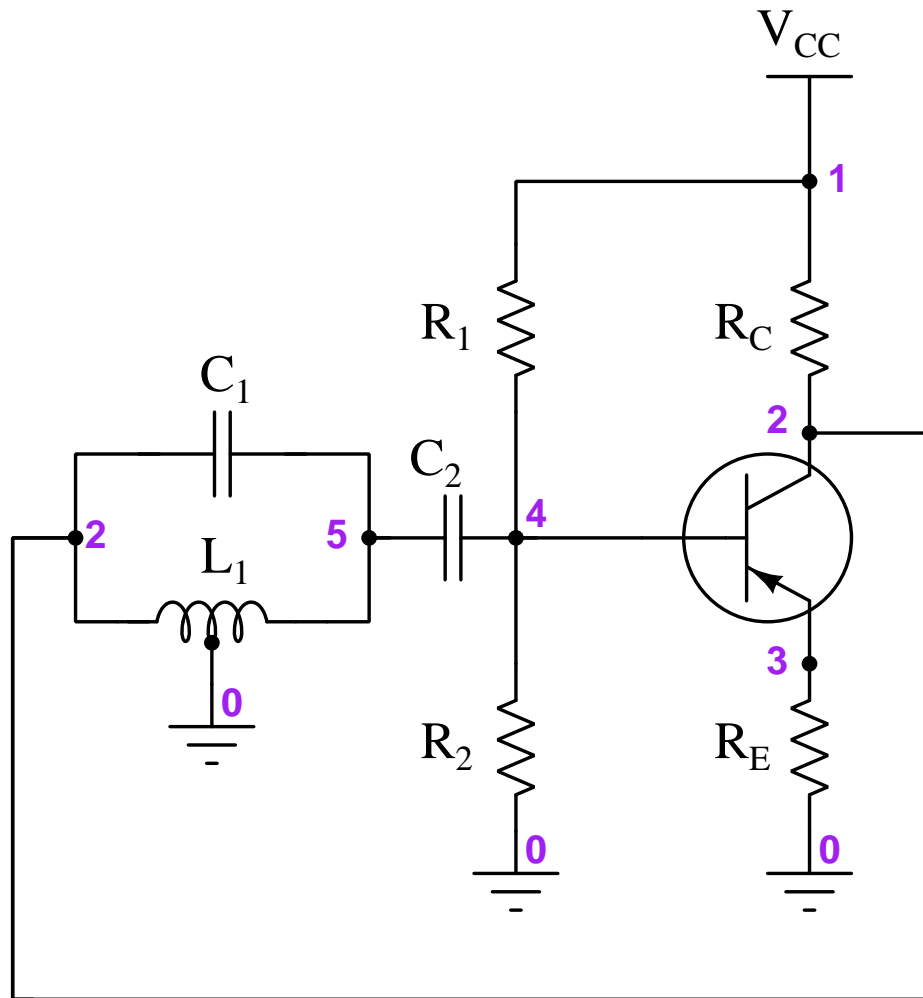
**Grading**

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

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

**Problem #5**

(Component values randomly chosen by instructor):

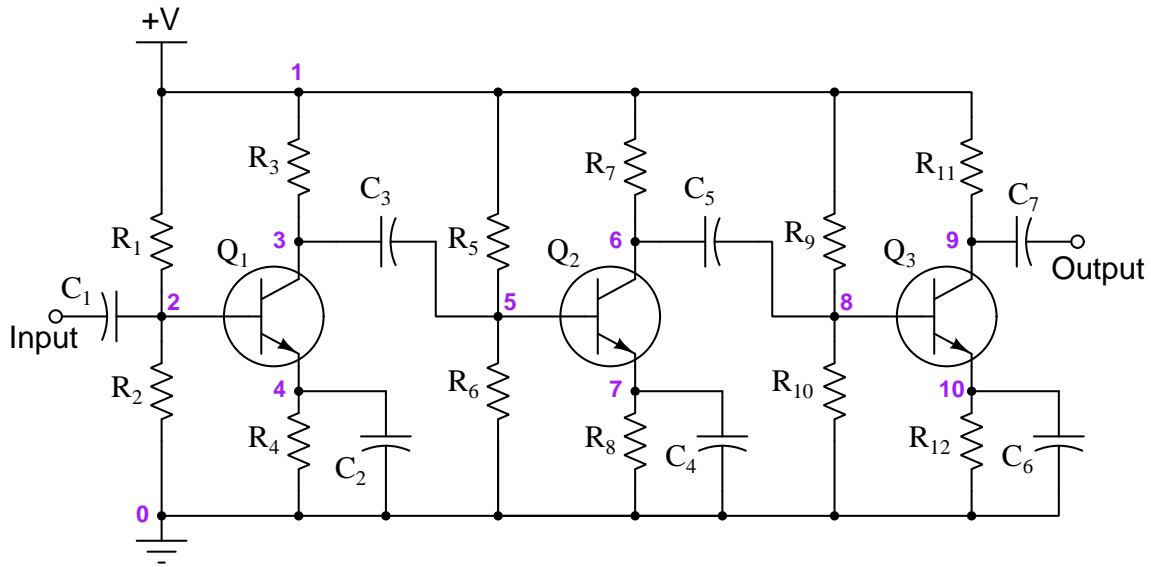
**Grading**

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

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

### Problem #6

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



### Grading

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

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



## Theory session 24

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

- (Question #1) Design and sketch a circuit using either a BJT or an FET to switch DC power to a load.  
*BJT behavior, FET behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks*
- (Question #2) Calculate voltages and currents in a series-parallel AC circuit.  
*Capacitive reactance, inductive reactance, impedance, complex-number arithmetic, properties of series networks, properties of parallel networks, Ohm's Law, Kirchhoff's Laws*
- (Question #3) Sketch a Thévenin equivalent network for a series-parallel DC resistor circuit.  
*Ohm's Law, Kirchhoff's Laws, ideal versus real sources, properties of series and parallel networks, Thévenin's Theorem, Norton's Theorem*
- (Question #4) Calculate the approximate gain for a multi-stage BJT amplifier circuit based on component values or signal measurements, expressed as both a ratio and a decibel figure.  
*Ohm's Law, BJT behavior, BJT amplifier behavior, gain calculations, decibels*
- (Question #5) Calculate voltages, currents, and/or power dissipations in a BJT or FET switching circuit.  
*Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior*
- (Question #6) Select appropriate components to set the frequency of an oscillator.  
*Ohm's Law, properties of series and parallel networks, resonance, tank circuits, Wein bridge networks*
- (Question #7) Determine possible faults in a discrete-transistor amplifier circuit.  
*Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, effects of opens vs. shorts, amplifier behavior*
- (Question #8 – REVIEW) Interpret amplitude values (peak, peak-peak, RMS), period values, phase shifts, and/or frequency values from an oscillograph display.  
*Oscilloscope operation, AC measurements, RMS vs peak ratios for sine and square and triangle/ramp waveforms*
- (Question #9 – REVIEW) Design and sketch an unloaded voltage divider network given required voltage and/or current values.  
*Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks*

## Theory session 25

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_c.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_c.pdf)

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

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

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

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

### Theory Session Expectations:

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

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

file wt\_0228

**Source text** – *Frequency-Domain Analysis* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_freqdomain.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_freqdomain.pdf)

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

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

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

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

### Theory Session Expectations:

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

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

file wt\_0113

## Theory session 27

**Source text** – *Transmission Lines* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_tline.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_tline.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “TDR cable fault testing” in the Conceptual Reasoning section of the Questions chapter.
- Complete “TDR calculator program in C” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Traveling-wave fault location on a power line” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- Animation of an open transmission line section of the Animations chapter.
  - Animation of a shorted transmission line section of the Animations chapter.
  - Animation of a terminated transmission line section of the Animations chapter.
  - Animation of a standing wave with full reflection section of the Animations chapter.
- file wt\_0037

**Source text** – *Basic Principles of Radio* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_radio.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_radio.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0160

## Theory session 29

**Source text** – *Radio Antennas* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_antenna.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_antenna.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Parabolic dish feed” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Antenna dimensions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Incorrect decibel calculation program” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0161

## Theory session 30

**Source text** – *Antenna Feed Systems* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_antennasystem.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_antennasystem.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Ultimate Transmatch” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Transformer impedance ratios” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Matching section calculator program” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0174

## Theory session 31

Source text – *RF Link Budgets* learning module

URL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_linkbudget.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_linkbudget.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0162



## Theory session 32

Source text – *RF Link Budgets* learning module

URL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_linkbudget.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_linkbudget.pdf)

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

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

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

- Make a formula note page listing every new formula you encounter, the necessary units of measurement, and a description of what it means
- Work through each representative example problem shown in the text, on your own, until your answers match the text’s. Avoid consulting the text for assistance unless absolutely necessary. *Unless and until you can do the problem(s) on your own, you have not yet learned the concept!*
- Carefully organize all your numerical results in link budget calculations, using either a table and/or a link budget graph!

### Theory Session Expectations:

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

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

file wt\_0173

## Theory session 33

**Source text** – *Introduction to Modulation* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_modulation.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_modulation.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Introduction to modulation
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation
  - Pulse modulation
  - Frequency-shifting
- Complete “Carrier-less radio” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Oscillographs comparing sinusoids” in the Quantitative Reasoning section of the Questions chapter.
- Examine the C++ code examples contained in the Modeling signal modulation using C++ section of the Programming References chapter, and explain how they simulate various types of signal modulation. Comment also on the differences you see between C++ and the more-familiar C programming language.

### Theory Session Expectations:

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

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

file wt\_0165

## Theory session 34

**Source text** – *High-Frequency Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_hfamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_hfamp.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Locate the Texas Instruments CC1190 datasheet for their 850-950 MHz “RF front end” IC (document SWRS089A revised February 2010, found in the **Datasheets/RF** directory of your EETREF document collection) and answer the following questions:
  - Examine the block diagram for this device and identify the function of each block within it, as well as the functions of all externally-connected components
  - Identify the functions of the three digital control pins (PA\_EN, LNA\_EN, and HGM) on this IC
  - Identify the maximum RF power output of this device’s power amplifier (PA) as well as its efficiency in percent
  - Identify whether this “front end” IC is designed for *balanced* or *unbalanced* RF signals
- Complete “Solid-state PA component functions” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Tank circuit calculator program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faults in a low-power CW transmitter” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0176

### Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. You are allowed to bring notes for reference, but not allowed to read them to your audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

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

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

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

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

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

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

## Foundational Concepts

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

Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	$R$ vs. $X$ vs. $Z$
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's Voltage Law	Behavior of transformers
Kirchhoff's Current Law	Transmission lines
Maximum Power Transfer Theorem	Heat transfer
Superposition Theorem	Modulation types
Thévenin's and Norton's Theorems	
Electric fields and capacitance	
Magnetic fields and inductance	
Conduction in semiconductors	
Behavior of PN junctions	
Behavior of BJTs	
Behavior of FETs	

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

### Problem #1

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

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

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

### Grading

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

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

### Problem #2

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

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

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

### Grading

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

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

### Problem #3

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

#### Grading

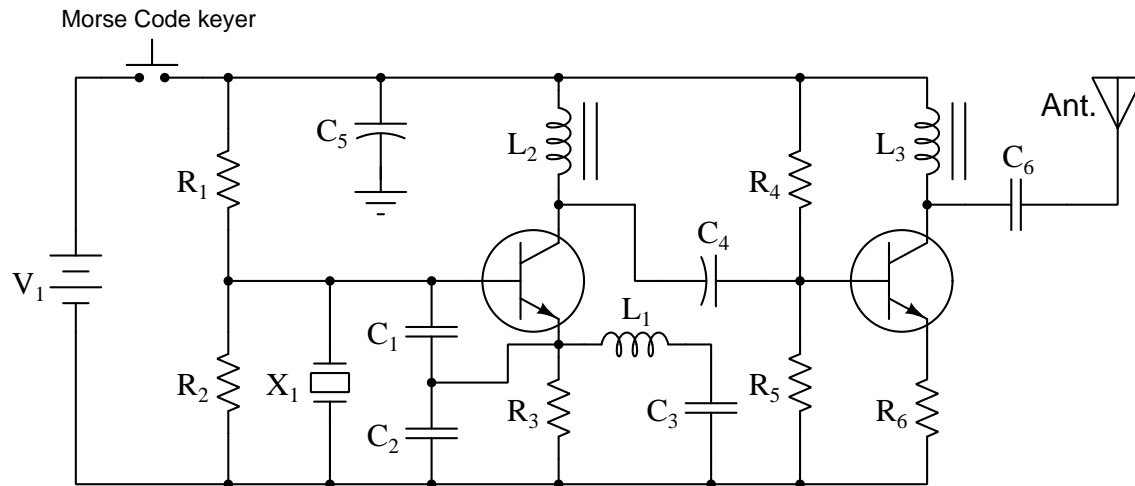
- ☐ [10%] Identify radiation pattern of first antenna
- ☐ [10%] Identify whether the feed line for the first antenna will be balanced or unbalanced
- ☐ [10%] Identify radiation pattern of second antenna
- ☐ [10%] Identify whether the feed line for the second antenna will be balanced or unbalanced
- ☐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

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



#### Problem #4

Analyze this radio circuit design:



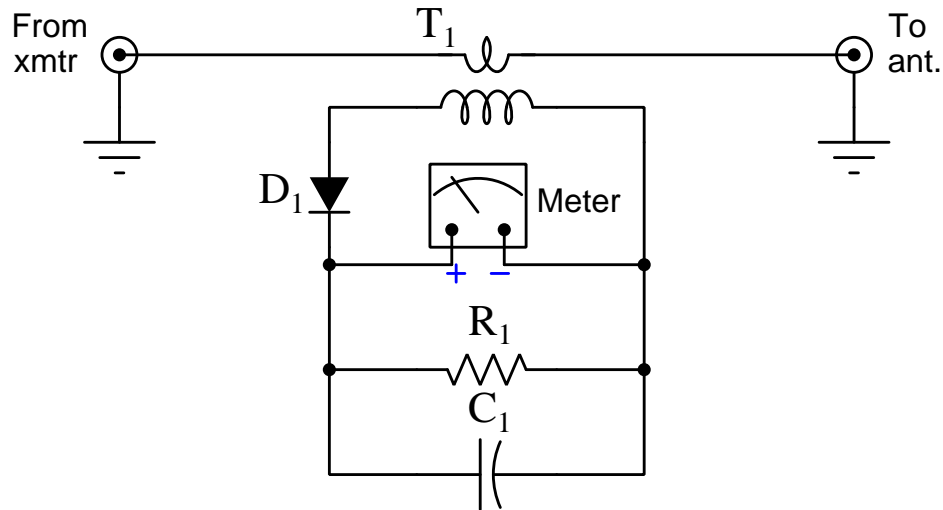
#### Grading

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

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

**Problem #5**

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

**Grading**

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

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

**Problem #6**

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

**Grading**

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

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

## Theory session 36

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

- (Question #1) Determine the appropriate dimensions for a radio antenna given signal frequency, or vice-versa.  
*Wavelength calculations, speed of light, antenna types and configurations (e.g. monopole, dipole, Yagi, loop), conversions between metric and imperial units of length*
- (Question #2) Compute power gains/losses in radio communication systems using decibels.  
*Decibels, power dissipation in RF cables, antenna gain, RF link budgets*
- (Question #3) Identify RF signal modulation based on oscillograph or spectrum displays.  
*Modulation schemes, AC quantities, oscilloscope display interpretation, spectrum analyzer display interpretation, sinusoidal decomposition (Fourier analysis), sidebands*
- (Question #4) Identify the effect of faults in a radio transmitter or receiver circuit.  
*Modulation and demodulation schemes, mixer circuits, effects of opens and shorts, oscilloscope display interpretation, spectrum analyzer display interpretation*
- (Question #5) Determine the length of a transmission line given reflectometry data, or vice-versa.  
*Velocity factor, speed of light, oscillograph display interpretation, conversions between metric and imperial units of length*
- (Question #6) Identify the purposes of individual components within an RF amplifier circuit, given a schematic diagram.  
*Transistor amplifier configurations (e.g. common-base, etc.), RF chokes, bypass capacitors, coupling, amplifier biasing*
- (Question #7) Determine necessary circuit parameters and/or configurations to properly match feedlines with other components (e.g. transceiver, antenna) in an RF system.  
*Transmission lines, standing wave ratio (SWR), transformer impedance ratios, quarter-wave matching sections, balun transformers, Maximum Power Transfer Theorem, Thévenin's/Norton's Theorems, velocity factor, speed of light*
- (Question #8 – REVIEW) Calculate voltages, currents, and/or powers in a transformer circuit  
*Transformer behavior, Ohm's Law, Joule's Law*
- (Question #9 – REVIEW) Apply right-triangle trigonometry to the solution of practical distance problems.  
*Law of sines, Pythagorean Theorem, sine function, cosine function, tangent function*

## Theory session 37

Source text – *Comparators* learning module

URL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_comparator.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_comparator.pdf)

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

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

### Theory Session Expectations:

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

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

### Additional resources:

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

file wt\_0050

## Theory session 38

Source text – *Feedback* learning module

URL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_feedback.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_feedback.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Miscalibrated speedometer” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Mathematical functions in feedback path” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Loss of servo feedback” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0042

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Differential inputs and outputs
  - Negative feedback
  - Regulation
  - Servos and control systems
  - Attenuated and offset feedback
- Complete “Fooling a voltage regulator” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Load current path” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Voltage follower simulation program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Internal faults in a TL082” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

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

file wt\_0043

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:  
→ Inverting and noninverting amplification
- Read, outline, and reflect on the Split DC power supplies section of the Derivations and Technical References chapter.
- Complete “Calculating output voltages and gains” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Necessary resistor values for specified voltage gains” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Calculating input and output voltages” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Effects of faults on a simple amplifier circuit” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
  - The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- file wt\_0044



## Theory session 41

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Differential amplification
  - Summation
- Complete “Vocal eliminator circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Subtractor calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Summer circuit calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Summer circuit simulation program” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
  - The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- file wt\_0114

## Theory session 42

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

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

### Theory Session Expectations:

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

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

### Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
  - The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- file wt\_0236

## Theory session 43

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0241

## Theory session 44

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

- Read, outline, and reflect on the following section of the Tutorial chapter:  
→ Integrators and differentiators
- Complete “Integrator calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Capacitor voltage simulation program” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

- Sections of the Case Tutorial chapter contain circuit examples which may serve as practice problems.
  - The Gallery chapter of the SPICE Modeling of Amplifier Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- file wt\_0240

## Theory session 45

**Source text** – *Operational Amplifiers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_opamp.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_opamp.pdf)

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

- Read, outline, and reflect on the following section of the Tutorial chapter:  
→ Oscillator circuits
- Practice analyzing circuit examples from today’s assigned reading, applying foundational concepts (e.g. KVL, KCL, Ohm’s Law, cardinal rule of negative feedback, etc.) wherever possible.
- Complete “Three-phase oscillator” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

### Additional resources:

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

file wt\_0242

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

EETREF/Tutorials/TI\_AnalogEngineers\_CircuitCookbook\_Amplifiers\_slyy137a.pdf

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

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

### Theory Session Expectations:

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

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

file wt\_0239

### Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. You are allowed to bring notes for reference, but not allowed to read them to your audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

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

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

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

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

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

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

## Foundational Concepts

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

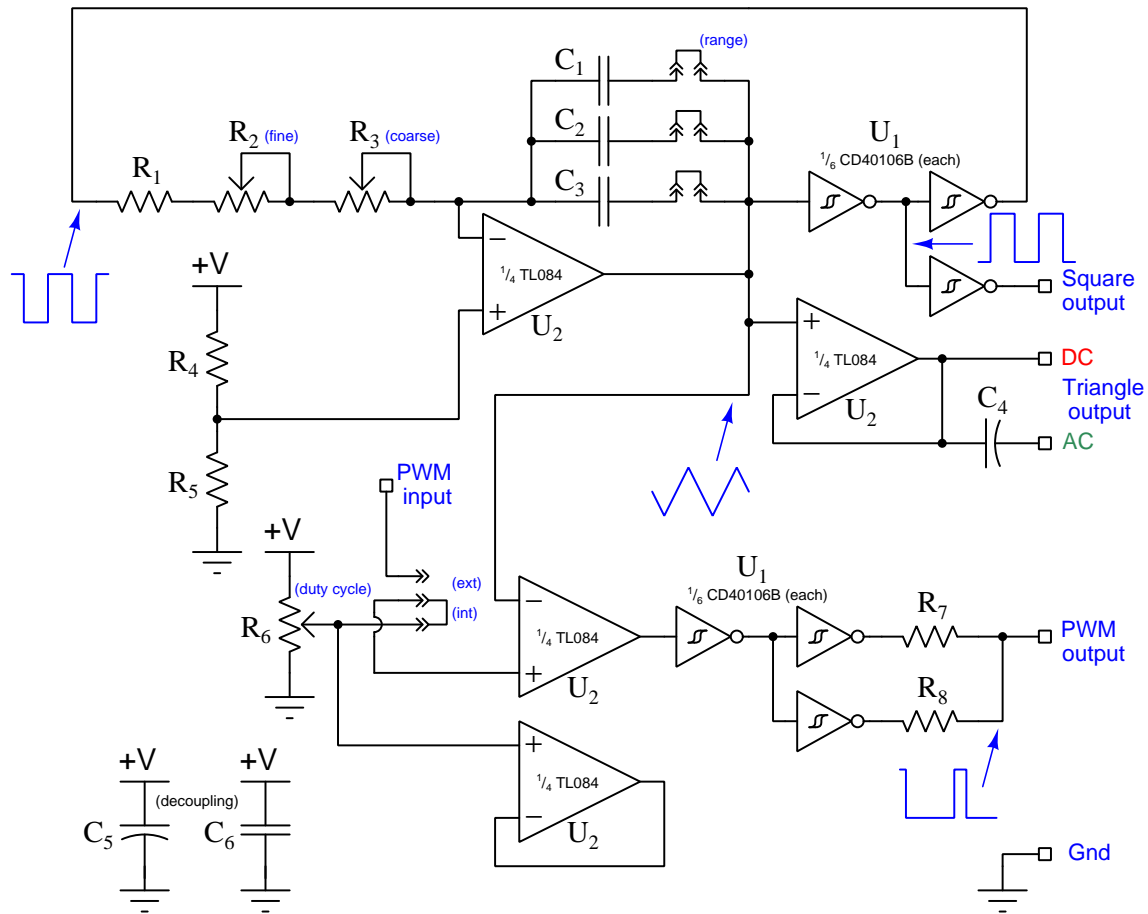
Conservation of Energy	Amplitude, period, frequency
Behavior of sources vs. loads	$R$ vs. $X$ vs. $Z$
Ohm's Law	Energy efficiency
Joule's Law	Power factor
Effects of opens vs. shorts	Resonance
Properties of series networks	Fourier analysis
Properties of parallel networks	Properties of filters
Kirchhoff's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

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



### Problem #1

Evaluate this signal generator circuit:



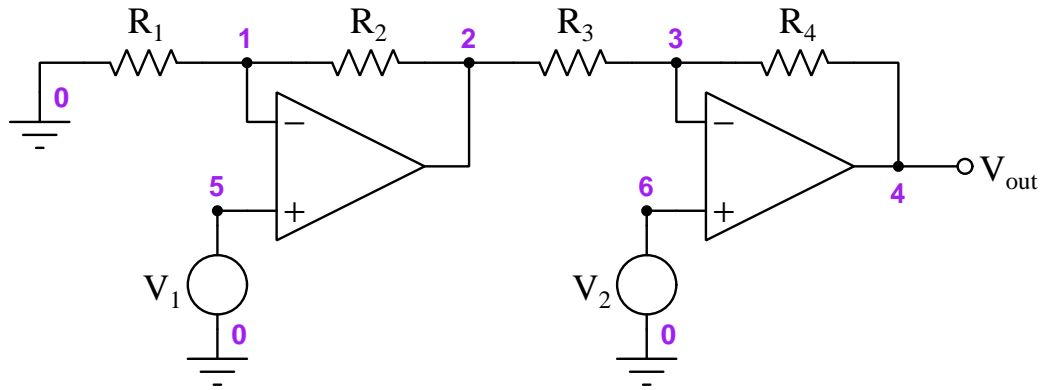
### Grading

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

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

**Problem #2**

(Component values randomly chosen by instructor):

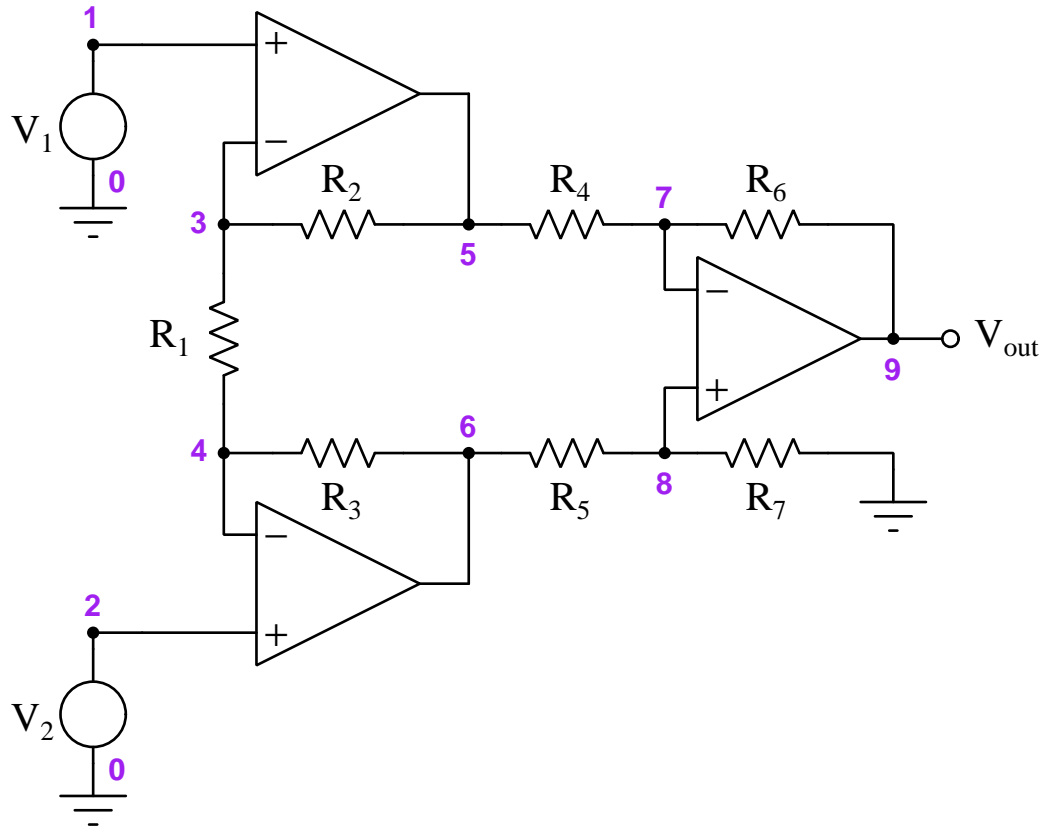
**Grading**

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

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

**Problem #3**

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

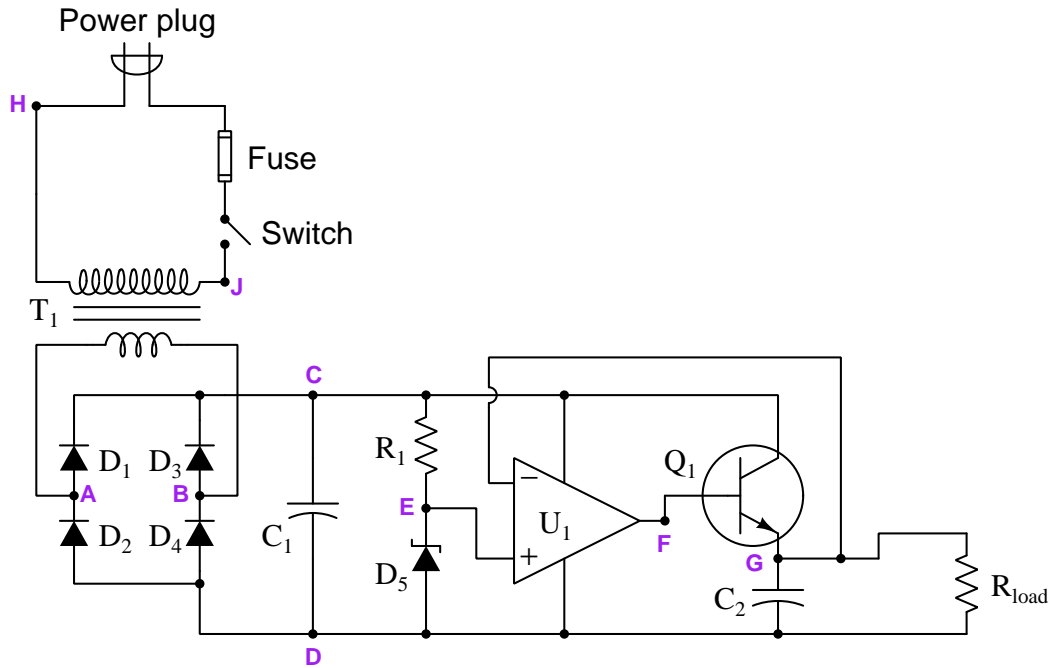
**Grading**

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

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

**Problem #4**

(Component values randomly chosen by instructor):

**Grading**

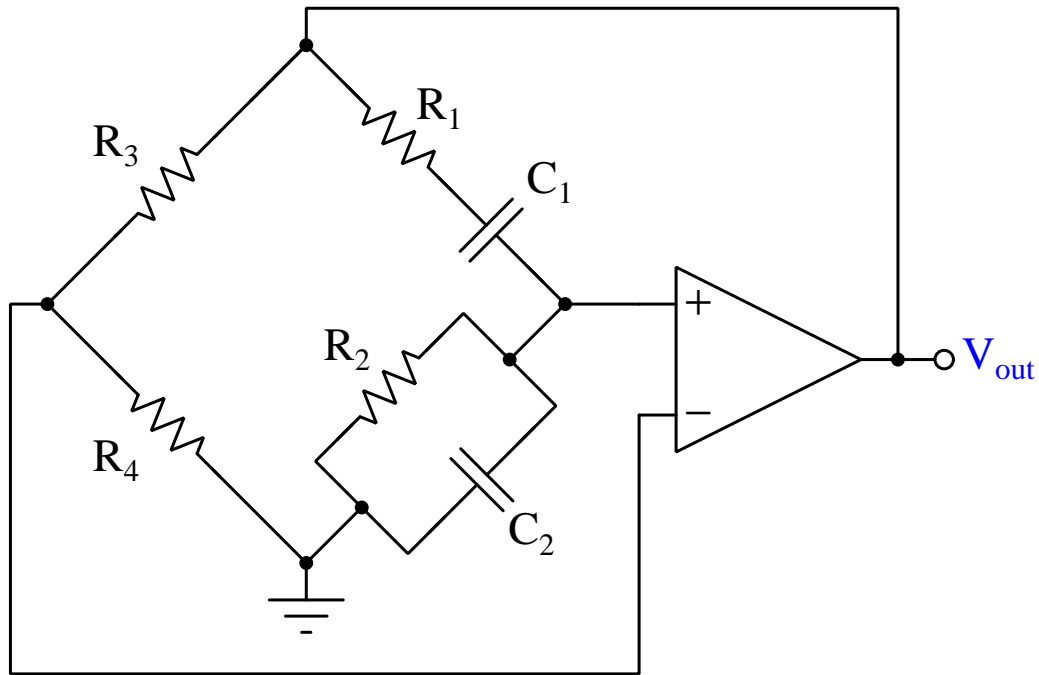
- ☐ [20%] Current magnitude and direction through resistor  $R_1$  ( $I_{R1}$ )
- ☐ [20%] Current magnitude and direction through load ( $I_{R_{load}}$ )
- ☐ [20%] Voltage magnitude and polarity between nodes F and G ( $V_{FG}$ )
- ☐ [20%] AC voltage magnitude between nodes A and B ( $V_{AB}$ )
- ☐ [20%] Power dissipation of voltage-reference diode ( $P_{D5}$ )

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

**Problem #5**

(Frequency randomly chosen by instructor):

### Wein-bridge oscillator

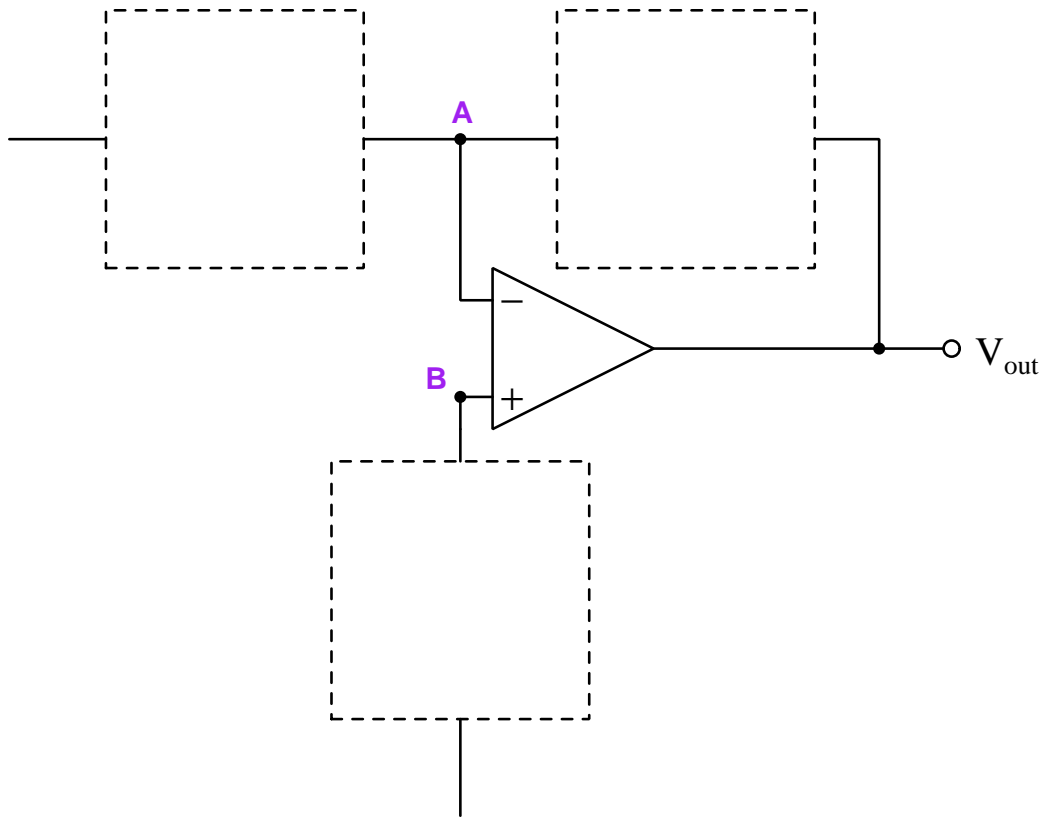
**Grading**

- ☐ [20%] Appropriate values for resistors  $R_1$  and  $R_2$ , between 1 k $\Omega$  and 100 k $\Omega$  each
- ☐ [20%] Appropriate values for resistors  $R_3$  and  $R_4$ , between 1 k $\Omega$  and 100 k $\Omega$  each
- ☐ [20%] Appropriate values for capacitors  $C_1$  and  $C_2$ , between 0.001  $\mu$ F and 1  $\mu$ F each
- ☐ [20%] Effect on output signal if \_\_\_\_ fails (*open* or *shorted*)
- ☐ [20%] Effect on output signal if \_\_\_\_ fails (*open* or *shorted*)

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

### Problem #6

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



### Grading

- ☐ [20%]  $V_{out}$  when  $V_{in} = \underline{\hspace{1cm}}$
- ☐ [20%] Opamp output terminal current when  $V_{out} = \underline{\hspace{1cm}}$
- ☐ [20%]  $V_A$  when  $V_{in} = \underline{\hspace{1cm}}$
- ☐ [20%]  $V_B$  when  $V_{in} = \underline{\hspace{1cm}}$
- ☐ [20%] Consequence of  $\underline{\hspace{1cm}}$  failing (*open* or *shorted*)

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

## Theory session 48

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

- (Question #1) Determine input parameters (e.g. voltage, current, resistance) necessary to drive a comparator-based circuit into a given output state.  
*Comparator behavior, Ohm's Law, Kirchhoff's Voltage Law, voltage dividers, Wheatstone bridge networks, shunt resistors for current measurement, AND/OR/NAND/NOR/XOR/NOT logic gate behavior*
- (Question #2) Design and sketch an operational amplifier circuit with a specified voltage gain.  
*Ohm's Law, general amplifier behavior, voltage gain, negative feedback, opamp behavior, inverting versus non-inverting opamp circuits*
- (Question #3) Calculate voltages and/or currents in a conventional summer or subtractor operational amplifier circuit.  
*Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, negative feedback, opamp summer circuits, opamp differential amplifier circuits*
- (Question #4) Calculate voltage and current values within an arbitrary operational amplifier circuit given component values and some given voltage and/or current values.  
*Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, BJT amplifier behavior, negative feedback, opamp behavior, comparator behavior*
- (Question #5) Calculate voltages and/or currents in an operational amplifier circuit conditioning a signal from a sensor or sensor network.  
*Wheatstone bridge networks, voltage dividers, Ohm's Law, Kirchhoff's Laws, properties of series and parallel networks, voltage and current for a capacitor, negative feedback, opamp behavior, comparator behavior, integrator and differentiator behavior, shunt resistors*
- (Question #6) Determine possible faults in a discrete-transistor or operational amplifier circuit.  
*Ohm's Law, Kirchhoff's Laws, Properties of series and parallel networks, effects of opens vs. shorts, amplifier behavior, negative feedback, opamp behavior*
- (Question #7 – REVIEW) Identify a passive filter circuit characteristic from its schematic diagram, and predict the effects of a component fault on that characteristic.  
*Properties of series networks, properties of parallel networks, effects of opens vs. shorts, filter circuit behavior, capacitive reactance, inductive reactance*
- (Question #8 – REVIEW) Sketch a Thévenin equivalent network for a series-parallel DC resistor circuit.  
*Ohm's Law, Kirchhoff's Laws, ideal versus real sources, properties of series and parallel networks, Thévenin's Theorem, Norton's Theorem*
- (Question #9 – REVIEW) Qualitatively predict voltage, current, and power changes in a series or parallel resistor circuit resulting from one component change.  
*Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, properties of voltage sources, properties of current sources*

## Theory session 49

**Source text** – *AC Induction Motor Starters* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_acstarter.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_acstarter.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Elementary motor starters
  - Latching motor starters
- Complete “Start/Jog control” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Microcontroller program for a simple motor starter” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Motor current calculations” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0195



## Theory session 50

**Source text** – *AC Induction Motor Starters* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_acstarter.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_acstarter.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Automatic motor starting
  - Inrush current
  - Inrush-limited starting
- Complete “Sketching connections for a three-phase starter” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Wye motor fed by Delta source” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Motor current simulation program” in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a relay-controlled motor (Circuit\_008) using **tshoot** software, and show the final results.
  - Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series/parallel networks, Kirchhoff’s Laws, etc.)

### Theory Session Expectations:

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

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

file wt\_0198

## Theory session 51

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_vfd.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_vfd.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Basic VFD function
  - AC motor braking
- Complete “Currents within a VFD circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Grinding machine braking” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Three-phase simulation program” in the Quantitative Reasoning section of the Questions chapter.
- Locate technical literature for a VFD with dynamic braking capability and identify the following information within the document(s):
  - Wiring diagram showing input AC power, connections to the motor, and where the braking resistor would connect
  - Ratings for motor drive power (voltage, current, and/or power in Watts)
  - Ratings for dynamic braking power (voltage, current, and/or power in Watts)

### Theory Session Expectations:

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

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

file wt\_0202

## Theory session 52

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_vfd.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_vfd.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0203

## Theory session 53

**Source text** – *Electrical Power Grids* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_grid.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_grid.pdf)

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
- Complete “Faults in a power system” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Pole-mounted transformers” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Multi-source grid simulation program” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faulted and unfaulted phasor diagrams” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0204

**Source text** – *Circuit Breakers and Disconnects* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_breaker.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_breaker.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0208

## Theory session 55

**Source text** – *Principles of Protective Relaying* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_prot\\_relay.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_prot_relay.pdf)

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
- Complete “Identifying protection zones” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Identifying which relays will pick up” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Median-select microcontroller program” in the Quantitative Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0108

## Theory session 56

**Source text** – *Instrument Transformers* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_pt\\_ct.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_pt_ct.pdf)

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
  - Potential transformers
  - Current transformers
  - Instrument transformer safety
  - Instrument transformer test switches
- Complete “Multi-ratio CT wiring” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Transformer-isolated voltage calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Damaged data acquisition system” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0209

## Theory session 57

**Source text** – *Overcurrent Protection Relays* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_50\\_51\\_relay.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_50_51_relay.pdf)

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

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

### Theory Session Expectations:

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

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

file wt\_0210



## Theory session 58

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

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_87GLB\\_relay.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_87GLB_relay.pdf)

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “87 line protection” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Faulted generator” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faulted 87 system” in the Diagnostic Reasoning section of the Questions chapter.

### Theory Session Expectations:

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

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

file wt\_0211

### Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. You are allowed to bring notes for reference, but not allowed to read them to your audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

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

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

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

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

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

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

## Foundational Concepts

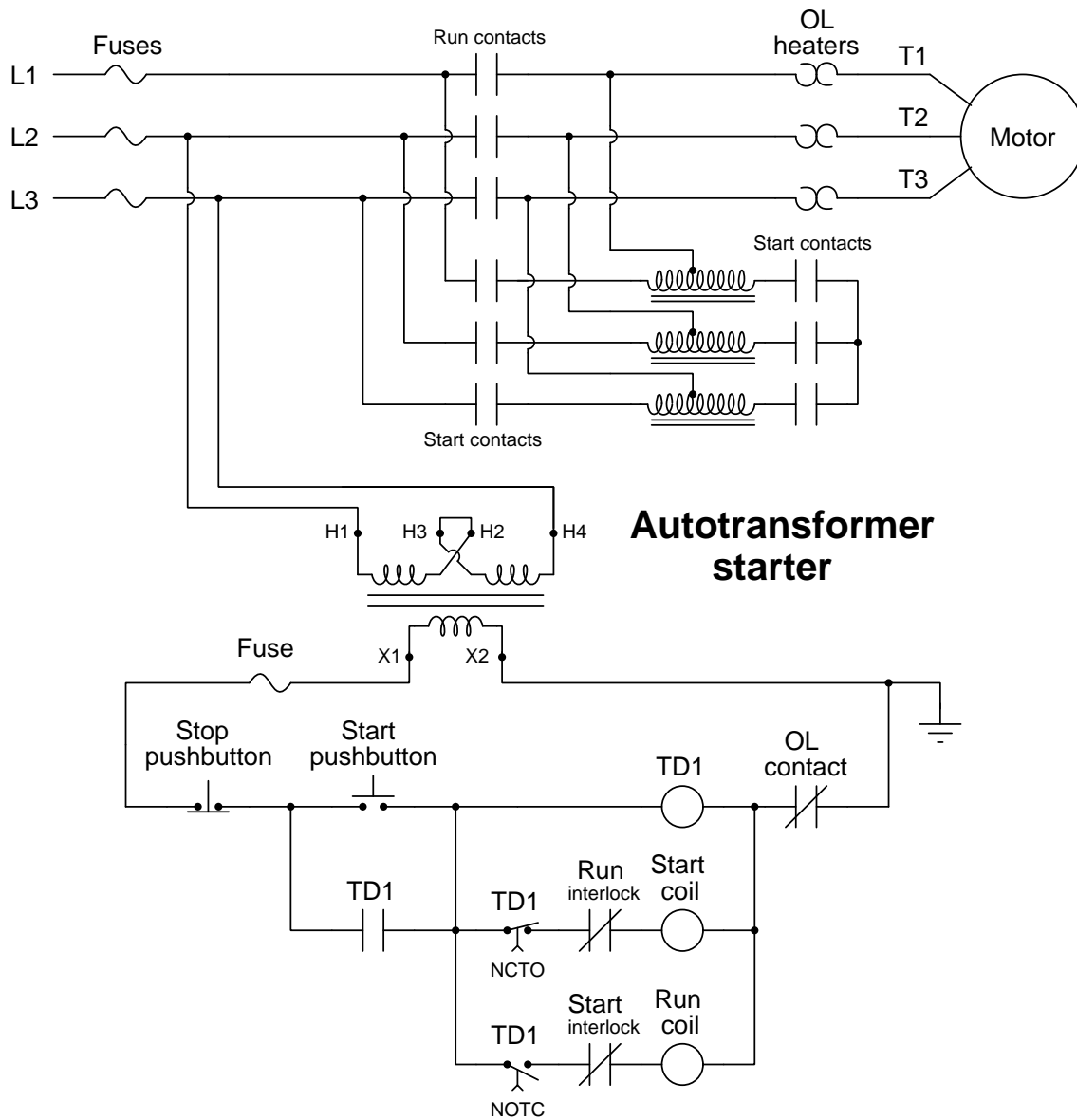
The following list shows foundational concepts related to prior topics of study. If you find yourself unable to solve any circuit-related problem, this list is a helpful means of reminding you which concepts might apply:

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

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

### Problem #1

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



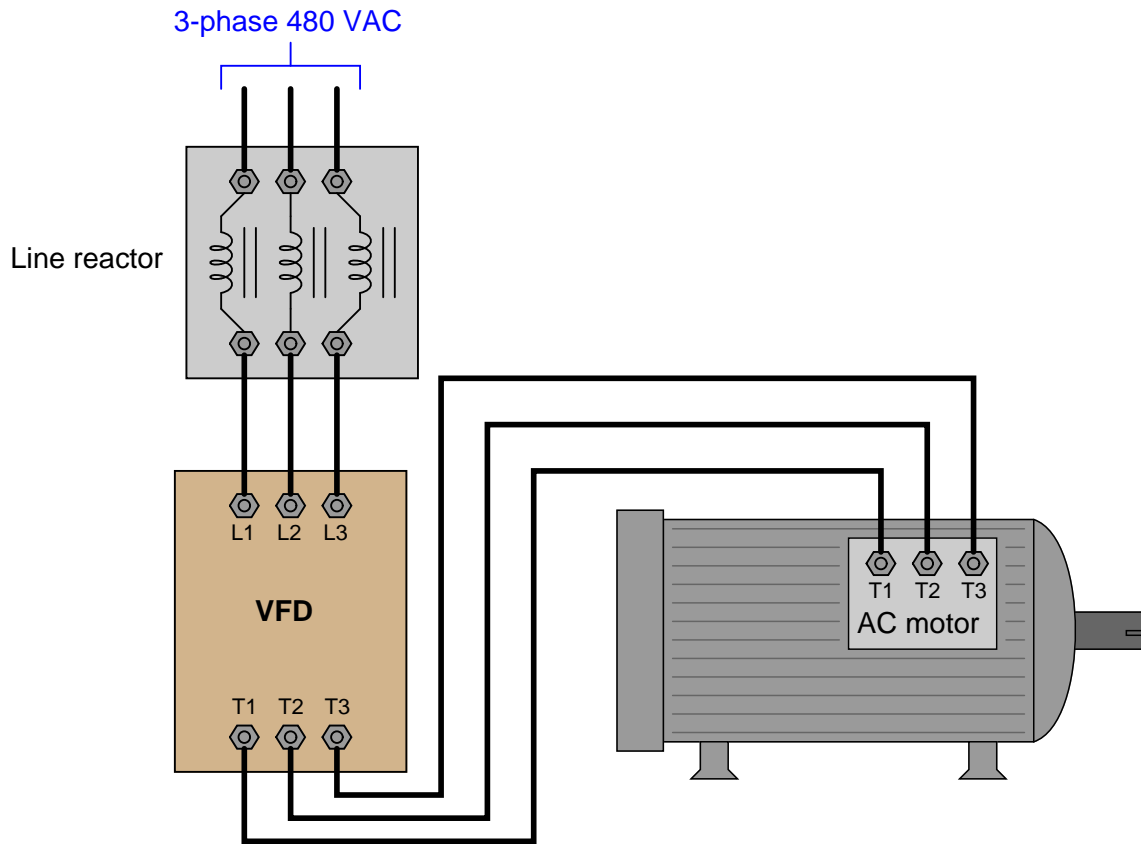
### Grading

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

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

### Problem #2

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



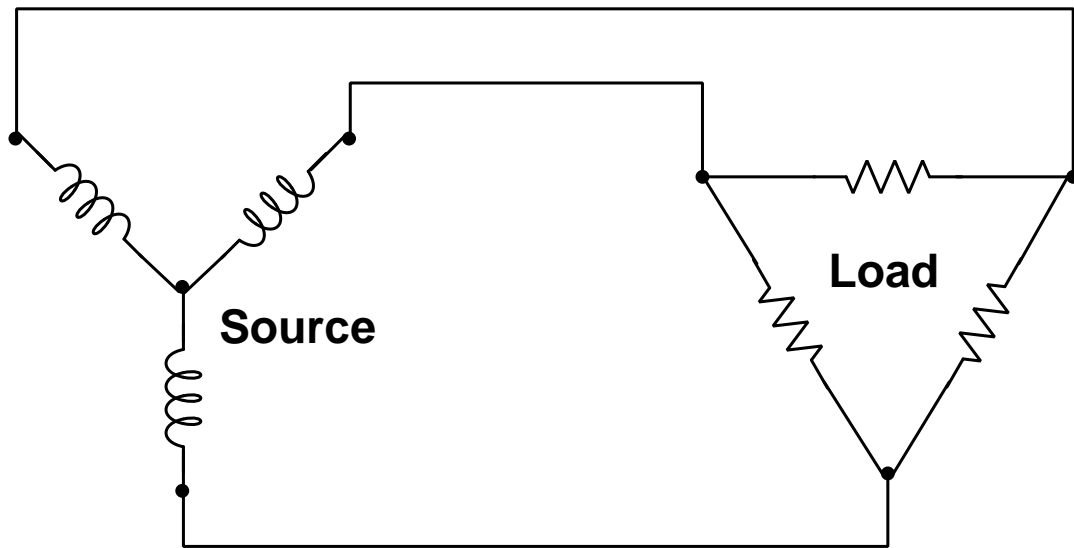
### Grading

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

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

**Problem #3**

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

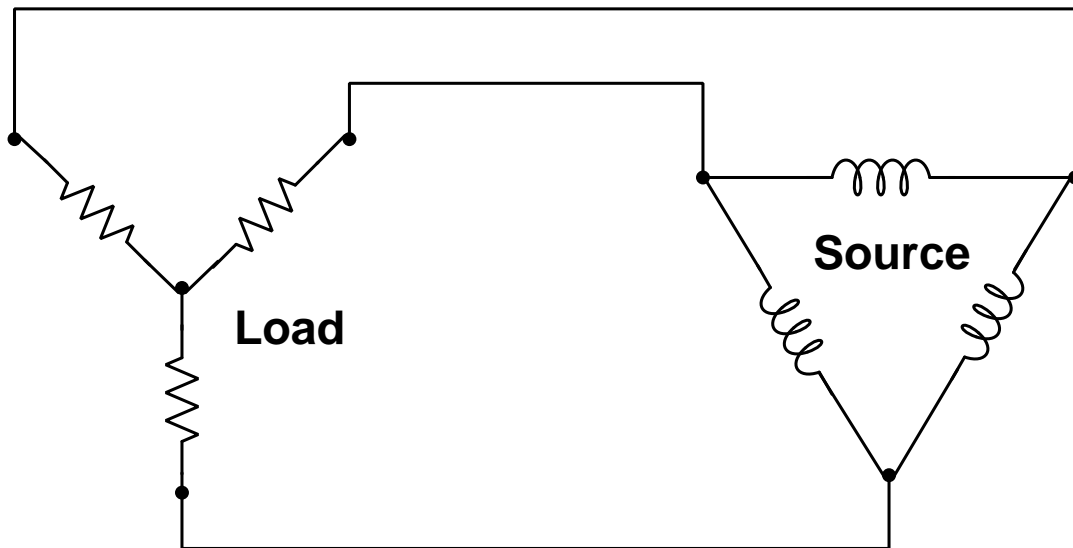
**Grading**

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

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

**Problem #4**

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

**Grading**

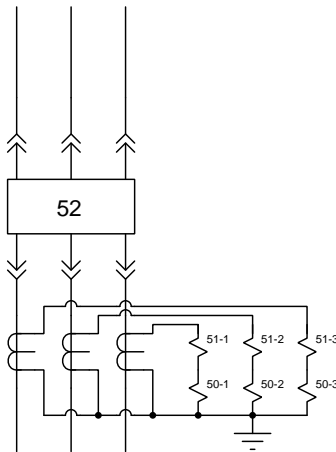
- [20% each] Calculate **five** of the unspecified parameters (student's choice)

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

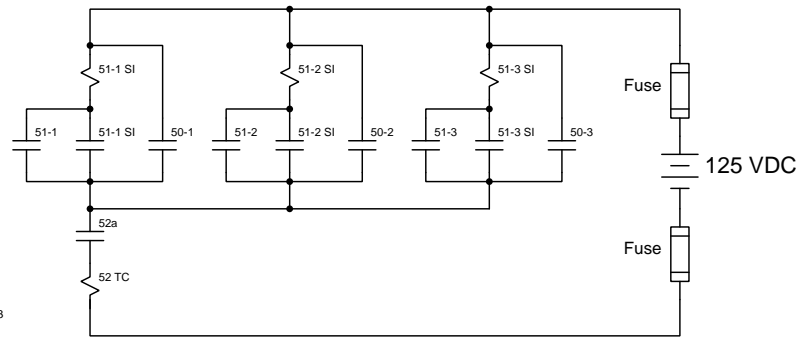
### Problem #5

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

Power diagram



Control diagram



CT ratio (each) = \_\_\_\_\_

$V_{line}$  = \_\_\_\_\_

$P_{load}$  (max) = \_\_\_\_\_

50 coil burden (each) = \_\_\_\_\_

51 coil burden (each) = \_\_\_\_\_

### Grading

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

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



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



## Theory session 60

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

- (Question #1) Sketch proper wire connections to form a working motor starter circuit.  
*Contactors behavior, ladder logic diagrams, three-phase motor control, industrial pushbutton switch function*
- (Question #2) Calculate voltage, current, resistance, and/or power in a balanced three-phase AC circuit  
*Properties of wye-connected networks, properties of delta-connected networks*
- (Question #3) Calculate voltages and/or currents within a three-phase protective relay circuit.  
*Properties of wye-connected networks, properties of delta-connected networks, complex numbers, phasor arithmetic, Ohm's Law, KVL, KVL, instrument transformers, 50/51 overcurrent relays, inverse-time trip functions, 87 differential current relays*
- (Question #4) Determine possible faults in a protective relay circuit.  
*Effects of opens vs. shorts, properties of wye-connected networks, properties of delta-connected networks, overcurrent protection, differential current protection, instrument transformer properties*
- (Question #5) Determine possible faults in a motor starter circuit.  
*Effects of opens vs. shorts, three-phase AC induction motors, ladder logic diagrams, BJT behavior*