

IETTI-101 – DC Circuit Theory (Semester 1 THEORY)

NAME: _____

Last update 10 March 2024

Session	Topic	Prep.	Part.	Comments
Session 01	Intro to the Career			
Session 02	V, I, R, basic concepts (I)			
Session 03	V, I, R, basic concepts (II)			
Session 04	Sources / loads, meters			
Session 05	Manipulating equations			
Session 06	Ohm's / Joule's Laws, etc.			
Session 07	Multimeters			
Session 08	Overcurrent protection			
Session 09	Conductors / connections			
Session 10	Electrical switches			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Prep.	Part.	Comments
Session 13	Series / V dividers			
Session 14	Parallel / I dividers			
Session 15	Kirchhoff's Voltage Law			
Session 16	Kirchhoff's Current Law			
Session 17	Series-parallel circuits (I)			
Session 18	Series-parallel circuits (II)			
Session 19	Bridge circuits			
Session 20	SPICE – resistor circuits			
Session 21	Qualitative circuit analysis			
Session 22	Elementary circuit design			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Prep.	Part.	Comments
Session 25	Ideal and real sources			
Session 26	Max power transfer theorem			
Session 27	Superposition theorem			
Session 28	Thévenin's / Norton's theorems			
Session 29	Electric and magnetic fields			
Session 30	Electromechanical relays			
Session 31	Capacitance and inductance			
Session 32	Capacitors / capacitive circuits			
Session 33	Inductors / inductive circuits			
Session 34	RC and LR circuit practice			
Session 35	ORAL PRESENTATIONS			
Session 36	EXAM			

NAME: _____

Session	Topic	Prep.	Part.	Comments
Session 37	Conductors, insulators, semi.			
Session 38	PN junctions / diodes			
Session 39	Bipolar junction transistors (I)			
Session 40	Bipolar junction transistors (II)			
Session 41	Field-effect transistors (I)			
Session 42	Field-effect transistors (II)			
Session 43	Transistor switching (I)			
Session 44	Transistor switching (II)			
Session 45	Transistor switching (III)			
Session 46	Thyristors			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Prep.	Part.	Comments
Session 49	Basic principles of digital			
Session 50	Relay ladder logic			
Session 51	Semiconductor logic gates			
Session 52	Digital diagnostic tools			
Session 53	Digital numeration (I)			
Session 54	Digital numeration (II)			
Session 55	Intro to PLCs			
Session 56	Digital codes			
Session 57	Combinational logic (I)			
Session 58	Combinational logic (II)			
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 teaches the theory of DC and basic digital logic circuits with an emphasis on physical conservation laws as unifying principles, including series-parallel network analysis, network theorems, electromagnetism, discrete semiconductor devices and switching circuits, basic digital electronics through combinational logic, and basic programmable logic controllers (PLCs). Students will also learn how to write SPICE netlists to simulate simple circuits. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

Course learning outcomes

- Compute voltages and currents in DC resistor circuits, resistor-capacitor and resistor-inductor time delay networks, diode and transistor switching circuits, and digital logic circuits given schematic diagrams, component values, and other circuit parameters. (Addresses Program Learning Outcomes 4, 6)
- Compute component values necessary to achieve stated performance goals in DC resistor circuits, time-delay networks, transistor switching circuits, and digital logic circuits. (Addresses Program Learning Outcomes 4, 6)
- Design and sketch simple resistor networks, time-delay networks, transistor switching circuits, and combinational logic circuits to meet stated functional requirements. (Addresses Program Learning Outcomes 4, 5, 6)
- Articulate and apply technical principles related to elementary circuit theory, SPICE circuit modeling, inverse-exponential decays, network theorems, semiconductor theory, digital logic, and digital numeration as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable faults in DC resistor networks, time-delay networks, discrete semiconductor switching circuits, and combinational logic 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)

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

Required Tools, Supplies, and Software

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

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

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

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

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

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

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

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

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

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

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

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

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

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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

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

- Read, outline, and reflect on the “What Is Electronics?” chapter of the *Career Guide* document
https://ibiblio.org/kuphaldt/socratic/model/mod_career.pdf
- Read the first two pages of your Theory course document
<https://ibiblio.org/kuphaldt/socratic/model/iETTI101.pdf>
- Read the first two pages of your Experiments course document (*only if you are enrolled*)
<https://ibiblio.org/kuphaldt/socratic/model/iETTI103.pdf>
- Read the first page of your Project course document (*only if you are enrolled*)
<https://ibiblio.org/kuphaldt/socratic/model/iETTI102.pdf>
- Bookmark all URLs listed below (in the **Important resources** section)

Complete the following *during* the scheduled session:

- Share what inspired you to enroll in this program
- Discuss what you read in the *Career Guide*
- Discuss time and effort necessary to succeed in this program:
 - Full load = 12 credits = 36 hours/week total time commitment + *General Education courses!*
 - Make *daily contact* with instructor, especially when absent ; check your email regularly
 - 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
- Discuss how theory sessions work, and how they differ from traditional lecture
- Identify the pre-work for *tomorrow's* theory session
- Identify “Required Tools, Supplies, and Software” to procure, and where to obtain
- [Optional] – sign FERPA release forms

Forms provided by the instructor for today's session:

- FERPA release form
- IETTI-101 Theory course document (printed from cover page through Theory Session 02)
- IETTI-103 Experiments course document (only if you are enrolled in this course as well)
- IETTI-102 Projects course document (only if you are enrolled in this course as well)

Important resources:

- <https://ibiblio.org/kuphaldt/socratic/model>, the *Modular Electronics Learning Project* web page containing all course documents, tutorials, and problem sets you will need in these courses
→ <https://ibiblio.org/kuphaldt/socratic/model/index#courses>, links to all IETTI course documents
- <https://ibiblio.org/kuphaldt/socratic/model/calendar.html>, our semester calendar showing dates for theory sessions, special events, and all-lab project sessions
- https://ibiblio.org/kuphaldt/socratic/model/daily_schedule.pdf, showing Monday-Friday class schedule
- 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 – *Voltage, Current, Resistance, and Basic Circuit Concepts* learning module

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

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

- Email your instructor so that they will know your email account is functional. If you would like your instructor to have multiple email addresses in case one service fails, carbon-copy (CC) those addresses.
- Read, outline, and reflect on the Simplified Tutorial chapter in its entirety.
 - List and define at least *four* important principles from the text (see the “Foundational concepts” part of the Conceptual Reasoning section for ideas), to be shared with your classmates and instructor during the theory session. Be sure to include page number references from the text for each of your terms and accompanying definitions.
 - Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Examine and reflect on the Example: A simple (working) circuit section of the Case Tutorial chapter, and answer the following questions:
 - Trace the direction of electric current in this circuit
 - What do the “+” and “–” symbols represent in this circuit?
- Examine and reflect on the Example: A continuity tester section of the Case Tutorial chapter, and answer the following questions:
 - List some common “conductive” substances
 - List some common “non-conductive” (i.e. “insulating”) substances
 - How do you suppose a *switch* works in a circuit to turn a lamp on and off?
- During today’s theory session, the instructor will demonstrate ways to write an effective outline, using today’s reading assignments as the source text. This exercise will be participatory, the instructor soliciting input from each of you as to what might go in this outline.
 - One sentence written for every paragraph read is a good default ratio to follow
 - Any confusing or unclear points should be noted by questions in the outline
 - Explore how to screen-capture and annotate images from the text for inclusion in the outline
 - We will time how long it takes to write a complete outline, determining an average number of minutes per page of text
- Make note that each module’s Case Tutorial chapter typically contains example problems fully worked out with solutions, thus providing practice problems for your own study above and beyond those problems normally assigned for you to solve as homework. Many Case Tutorial examples also serve as good suggestions for experiments (e.g. the IETTI-103 course).

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 – *Voltage, Current, Resistance, and Basic Circuit Concepts* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
 - Devote one whole page of your outline to a summary of key concepts. For a list of suggested concepts to define on your summary page, refer to the “Foundational concepts” subsection of the Conceptual Reasoning section of the Questions chapter. Note: every learning module contains a “Foundational concepts” list, and it serves as a good self-check of your Tutorial reading that you can confidently define each of those concepts.
- During today’s theory session we will once again explore strategies for outlining a text.
 - Find places in the Case Tutorial example “Potential in open and shorted circuits” where the words relate to specific images, and then annotate those images with clarifying notes showing what the words describe
 - Referencing the non-faulted electric circuit diagram, identify two things: (1) the direction that electric *charge carriers* move in that circuit, and (2) the direction that *energy* moves in that circuit
- Complete “Applying foundational concepts to a two-lamp circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Polarities in a multi-lamp circuit” in the Conceptual Reasoning section of the Questions chapter.

Theory Session Expectations:

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

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

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Theory session 04

Source text – *Source and Loads, Voltmeters and Ammeters* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
 - Go to the Introduction chapter and find the itemized list of suggested questions to ask yourself when studying this subject. Pick any *two* of these questions and write your answers to them. Note: every learning module contains a list of such questions in the Introduction chapter, and it serves as guide for close reading of the Tutorial.
- Examine and reflect on the Example: money analogy for voltage section of the Case Tutorial chapter, and answer the following question:
 - What would be different if the person began with \$738 in their pocket at point A rather than \$38, but withdrew the same amount of cash from the bank and spent the same amounts of money at the movie theater and store that they did before? How would all the dollar figures change in the illustration? Would the “money meters” register any differently?
- Complete “Source and load annotations” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Applying foundational concepts to a solar-powered motor” in the Conceptual 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 course document listing *Required Tools, Supplies, and Software* and identify what you will need to obtain for the courses you are currently enrolled in.

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 Case Tutorial chapter contains examples helpful to understanding these topics!
 - The Gallery chapter of the SPICE Modeling of Resistor 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_0006

Theory session 05

Source text – *Manipulating Algebraic Equations* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - The “equals” symbol
 - Addition and subtraction
 - Multiplication and division
 - Proper order of operations
 - Factoring
 - Reciprocation
 - Powers and roots
- Complete “Solving for n ” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Manipulating the kinetic energy equation” in the Quantitative Reasoning section of the Questions chapter.
- If time permits, install any remaining free software needed for this semester (e.g. Python, `tshoot`).

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_0063

Source text – *Ohm's and Joule's Laws, Resistor Ratings, and Electrical Safety* learning module

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

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

- If you haven't already, purchase a simple scientific calculator (*the TI-36X Pro is highly recommended*). Top-end TI calculators (e.g. TI-89) are more than capable of performing all the arithmetic you'll ever need, but can also be unnecessarily cumbersome to operate. You definitely want a hand calculator that easily accepts and displays numerical values in "engineering" notation (or with metric prefixes), and also has ample memory locations to store and retrieve results.
- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
 - Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Examine the circuit examples shown in the Case Tutorial chapter, and identify which of those apply Ohm's Law. Note: many of the learning modules you will be reading contain a Case Tutorial chapter with worked examples of circuits, serving as confirmation of principles taught in the other tutorial(s) as well as problems for your own practice.
- Read, outline, and reflect on the Metric prefixes section of the Derivations and Technical References chapter.
 - Demonstrate how to enter metric prefixes in your scientific calculator
 - Describe the common error made by students new to metric prefixes that is explained in the text
- Complete "Assessing shock hazards in a circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Power, Voltage, Current, and Resistance calculations" in the Quantitative Reasoning section of the Questions chapter.

If time permits during the theory session, run some destructive tests of resistor over-powering in the lab using $\frac{1}{4}$ Watt resistors of various values and a DC voltage source. Determine how much a resistor needs to be over-powered for it to show immediate signs of distress.

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_0091

Theory session 07

Source text – *Multimeters* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Analog versus digital meters
 - Voltage, current, and resistance
 - Series versus parallel connections
 - Measuring voltage
 - Measuring current
 - Measuring resistance
 - Ranges and scales

NOTE: a common source of confusion for students is the interpretation of analog (VOM) meter scales. A helpful suggestion here, and good advice for better understanding all mathematical presentations in textbooks, is to do your best to explain the worked examples shown in the text. In this case, the page within the Ranges and scales section showing the VOM photograph with multiple bullet-listed interpretations of the pointer's position (depending on the range selection) is an excellent one to study closely. Carefully identify which scale on the meter's face is the appropriate one to read based on the specified range setting, then compare the pointer's position on that scale with the italicized "answer" showing the proper reading within that range until you see the pattern(s). Don't consider yourself to have understood this concept until you can reliably make those same interpretations!

- Complete "Applying foundational concepts to multimeter usage" in the Conceptual Reasoning section of the Questions chapter.
- Complete "VOM measurement interpretation" 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_0127

Theory session 08

Source text – *Overcurrent Protection* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
 - Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Complete “Applying foundational concepts to a fused circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Interpreting a fuse curve” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Failed motor circuit” in the Diagnostic Reasoning section of the Questions chapter.
- Run at least one simulation of a simple one-resistor circuit with DC voltage source (circuit_000) 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, Ohm’s Law, etc.)

Additionally, research and be ready to present on specific details of IETI 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_0105

Theory session 09

Source text – *Conductors and Electrical Connections* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_connect.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:
 - Making and breaking connections
 - Connection resistance
 - Wire size and type
 - Permanent connections – Solder
 - Permanent connections – Compression connectors
 - Permanent connections – Terminal blocks
 - Temporary connections – Solderless breadboards
- Complete “Switch contact size” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Power losses over wires” in the Quantitative Reasoning section of the Questions chapter.
 - *Hint: write all the equations you’ve learned and all the foundational concepts you’ve learned so far for electric circuits, and use these as “check-lists” for ideas of things to try when analyzing this circuit! Remember that all calculations must be kept in context!!*
- Complete “Testing for a broken connection” in the Diagnostic Reasoning section of the Questions chapter.

Check for an electronic message from your instructor containing a “practice” exam to help you prepare for the real written exam on theory session 12!

Some advice: *Never consider yourself to have learned a concept unless and until you can reliably apply it to situations you have never seen before, without assistance from anyone else!* What are some good ways to check your own preparedness for upcoming assessments in this course such as oral presentations and written exams? What strategies and resources would help your self-assessment so you’ll know you’re prepared?

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 Case Tutorial chapters contained within learning modules contains examples of that module’s concepts and principles applied to practical problems, complete with correct analyses and results. These serve as excellent practice problems when preparing for oral presentation challenges and written exams: simply try to solve the problems shown, and then check against the given answers/results to see if yours are correct.
- Using a soldering iron section of the Animations chapter.
file wt_0092

Theory session 10

Source text – *Electrical Switches* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
 - Write a question of your own based on information contained in the text, to be shared with your classmates and instructor during the theory session.
- Complete “Positive versus negative switch location” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Sketch a lamp control circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Switch states” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Oven control switches” 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_0139

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:

Check-list of Foundational Concepts

- ☐ Conservation of Energy
- ☐ Conservation of Electric Charge
- ☐ Behavior of sources versus loads
- ☐ Ohm's Law
- ☐ Joule's Law
- ☐ Effects of opens versus shorts

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

Solve for ___ in the following equations:

$$-5 = 3x - w + y$$

$$4 = \frac{a + 9c}{b}$$

$$10 = \frac{-q}{w + v}$$

$$20 = \sqrt{t - x} - f$$

$$-9 = h(a - c)^2$$

Grading

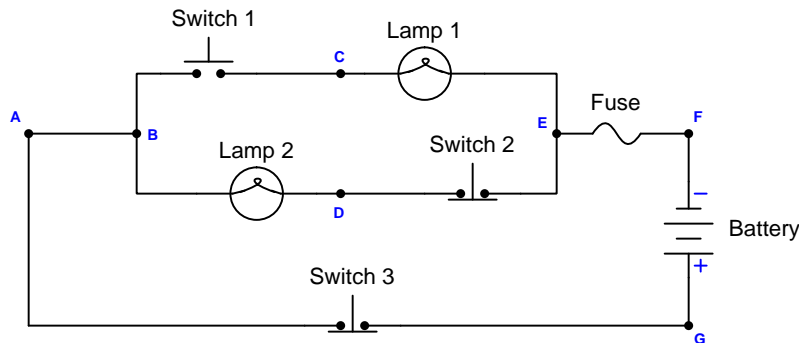
- ☐ [20%] Correct result for first equation
- ☐ [20%] Correct result for second equation
- ☐ [20%] Correct result for third equation
- ☐ [20%] Correct result for fourth equation
- ☐ [20%] Correct result for fifth equation

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

Problem #2

Determine whether or not the faults listed in the grading criteria could be possible for this circuit assuming the following symptoms:

Instructor describes behaviors of both lamps under various switch pressed/unpressed conditions, as well as at least one diagnostic voltage measurement. For example, “Lamp 1 functions properly but Lamp 2 only de-energizes when Switch 3 is pressed; 0 Volts measured between E and F with all switches unpressed”.



Identify the likelihood of each specified fault. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault is compatible with *all* measurements and symptoms in this circuit.

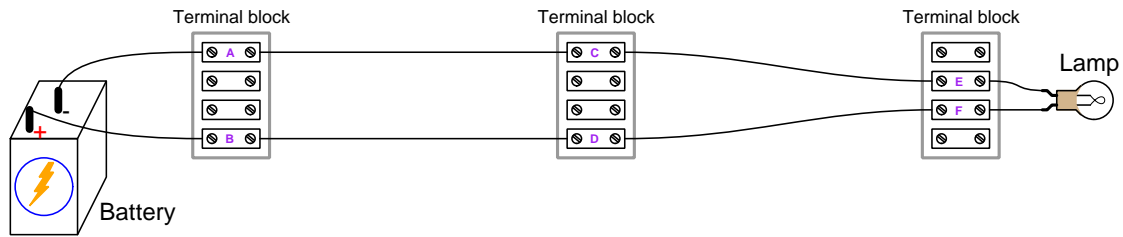
Grading

- ☐ [10%] Lamp 1 failed open?
- ☐ [10%] Lamp 2 failed open?
- ☐ [10%] Lamp 2 failed shorted?
- ☐ [10%] Switch 1 failed open?
- ☐ [10%] Switch 2 failed open?
- ☐ [10%] Switch 3 failed open?
- ☐ [10%] Switch 1 failed shorted?
- ☐ [10%] Switch 2 failed shorted?
- ☐ [10%] Switch 3 failed shorted?
- ☐ [10%] Fuse blown?

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

Problem #3

Identify the effects of a (*open/shorted*) fault between points ___ and ___ on the following voltages and currents in this circuit:



Grading

- ☐ [20%] Current through terminal A (I_A)
- ☐ [20%] Current through terminal F (I_F)
- ☐ [20%] Voltage between points C and D (V_{CD})
- ☐ [20%] Voltage between points C and F (V_{CF})
- ☐ [20%] Voltage between points B and D (V_{BD})

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

Problem #4

Calculate the following electrical quantities in a simple one-source, one-resistor circuit given the other parameters:

- $V = 15 \text{ V}$; $I = \underline{\hspace{1cm}} \text{ A}$; $R = ???$
- $R = 250 \Omega$; $V = \underline{\hspace{1cm}} \text{ V}$; $I = ???$
- $V = 9 \text{ V}$; $R = \underline{\text{(4-band color code)}}$; $I = ???$
- $I = 3.2 \text{ A}$; $P = \underline{\hspace{1cm}} \text{ W}$; $V = ???$
- $R = 50 \Omega$; $V = \underline{\hspace{1cm}} \text{ V}$; $P = ???$

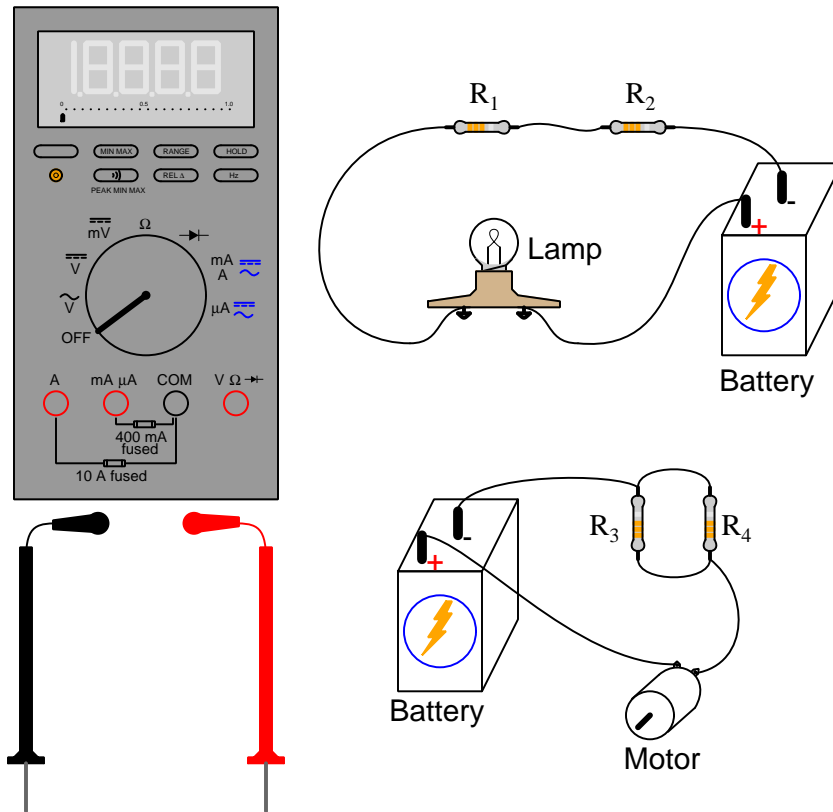
Grading

- ☐ [20%] Correct quantity and units of measurement for first scenario
- ☐ [20%] Correct quantity and units of measurement for second scenario
- ☐ [20%] Correct quantity and units of measurement for third scenario
- ☐ [20%] Correct quantity and units of measurement for fourth scenario
- ☐ [20%] Correct quantity and units of measurement for fifth scenario

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

Problem #5

Identify the proper multimeter function, test jacks, and red/black probe connections to measure the following quantities in these circuits as unobtrusively as possible, assuming each circuit is designed such that the lamp draws ____ of current and the motor draws ____ of current:



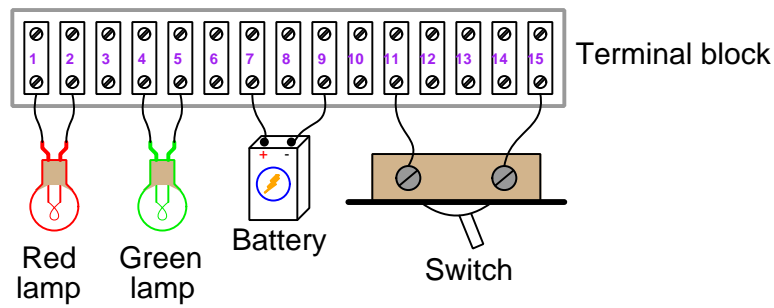
Grading

- ☐ [20%] Measure current through resistor R_1
- ☐ [20%] Measure voltage across resistor R_2
- ☐ [20%] Measure resistance of R_2
- ☐ [20%] Measure current through resistor R_3
- ☐ [20%] Measure voltage across resistor R_4

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

Problem #6

Sketch wires connecting the terminals on the terminal block to form working circuits:



Grading

- ☐ [20%] Proper wire connections to energize the red lamp with no switch control
- ☐ [20%] Proper wire connections to energize the green lamp with no switch control
- ☐ [20%] Proper wire connections to control the red lamp with the switch
- ☐ [20%] Proper wire connections to control the green lamp with the switch
- ☐ [10%] Correctly answer question from audience
- ☐ [10%] Correctly answer question from audience

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

Problem #7

Answer the following questions about course policies and grading, based on what you find within the course documents themselves. You are welcome and encouraged to show where in these documents you were able to find answers.

Grading

- ☐ [10%] Compute the over-all percentage score for a Theory course such as IETTI-101 given the following Oral Presentation scores (_____, _____, _____, _____, _____) and the following Written Exam scores (_____, _____, _____, _____, _____)
- ☐ [10%] How much would be deducted from the over-all course score computed above for arriving unprepared to Theory course sessions on _____ different occasions?
- ☐ [10%] Identify at least two proven advantages of using the “inverted” method of instruction rather than lecture in Theory courses
- ☐ [10%] Identify at least two behaviors that will result in a failing grade for a Theory course
- ☐ [10%] Cite any *two* of the seven EET Program Learning Outcomes and explain why they are relevant to success in Electronics-related careers based on some of the career options we explored in theory session 01 (from the *Career Guide* document)
- ☐ [10%] How may you earn full credit for preparation and participation if you must be absent for a Theory session?
- ☐ [10%] The first page of every written exam contains a brief explanation of how these “mastery” exams function. What is necessary to pass one of these exams?
- ☐ [10%] Identify at least two effective ways to prepare for mastery exams
- ☐ [10%] How closely must numerical answers be to the instructor’s answer key to receive full credit on an exam question?
- ☐ [10%] This entire program is designed to place students in roles of high responsibility: students responsible for gathering information from books rather than having the instructor orally recite the information for them; students responsible for designing their own experiments rather than having pre-scripted lab activities given to them; students responsible for presenting their own solutions rather than having pre-engineered solutions given to them; etc. *What purpose is served by placing this level of responsibility on students?*

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 simple circuit given necessary as well as extraneous parameters.
Ohm's Law, Joule's Law, resistor 4-band color codes
- (Question #2) Determine the nominal, low, and high resistance values for four-band resistors given their band colors.
Resistor 4-band color codes, percentage calculations, tolerance
- (Questions #3 and #4) Identify the presence or absence of voltage between specified pairs of points in a single-source, single-load circuit.
Electrically common points, electrically distinct points, voltage, tracing current in a circuit, sources versus loads
- (Question #5) Identify voltage polarity given current direction, and current direction given voltage polarity, for both sources and loads. Also, identify sources versus loads given voltage polarity and current direction.
Voltage, current, behavior of sources vs. loads
- (Question #6) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
Voltage, current, behavior of sources vs. loads, multimeter usage
- (Question #7) Determine possible faults in an elementary circuit.
Voltage, current, effects of opens vs. shorts, behavior of sources vs. loads, normally-open and normally-closed switch behavior

Theory session 13

Source text – *Series Circuits and Voltage Dividers* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
→ Perform one of the example circuit analyses shown in the text, showing your own work and how you arrived at the same conclusions as the text. *The purpose of this is to practice a highly effective technical reading and study habit – see the NOTE below for details.*
- Complete “Explaining the meaning of calculations” in the Conceptual Reasoning section of the Questions chapter.
- Complete “VIRP table for a three-resistor series circuit” in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a three-resistor voltage divider (circuit_001) using `tshoot` software, and show the final results.
→ Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series networks, Ohm’s Law, etc.)

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

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

Theory Session Expectations:

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 Resistor 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!
- `tshoot` circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_001.

file wt_0094

Theory session 14

Source text – *Parallel Circuits and Current Dividers* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
 - Perform one of the example circuit analyses shown in the text, showing your own work and how you arrived at the same conclusions as the text. *The purpose of this is to practice a highly effective technical reading and study habit – see the NOTE below for details.*
- Complete “Explaining the meaning of calculations” in the Conceptual Reasoning section of the Questions chapter.
- Complete “VIRP table for a three-resistor parallel circuit” in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a three-resistor current divider (circuit_002) using `tshoot` software, and show the final results.
 - Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of parallel networks, Ohm’s Law, etc.)

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

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

Theory Session Expectations:

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 Resistor 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!
- `tshoot` circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_002.

file wt_0095

Theory session 15

Source text – *Kirchhoff's Voltage Law* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_kv1.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 “Tracing KVL loops in a series circuit” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.
- Complete “Tracing KVL loops in a multi-source circuit” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.
- Complete “Voltages in a resistor network” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.

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

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

Theory Session Expectations:

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 Resistor 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_0007](#)

Theory session 16

Source text – *Kirchhoff's Current Law* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_kcl.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 “Three-wire electrical power distribution” in the [Conceptual Reasoning](#) section of the [Questions](#) chapter.
- Complete “Battery currents” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.
- Complete “Mysterious fuse failure” in the [Diagnostic Reasoning](#) section of the [Questions](#) chapter.
- If time permits, solve more Kirchhoff's Voltage Law problems from the previous module ([mod_kv1.pdf](#)), and/or run simulations in `tshoot` for the three-resistor voltage divider circuit (Circuit_001) using the `-nofault` start-up option where you may predict the amount of voltage between different pairs of test points in the circuit and then measure those voltages to test your predictions.

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

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

Theory Session Expectations:

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 Resistor 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_0008](#)

Theory session 17

Source text – *Series-Parallel Circuits* learning module

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

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

- Read, outline, and reflect on the Simplified Tutorial chapter in its entirety.
 - Write a summary page listing the characteristics of series networks, and another summary page listing the characteristics of parallel networks: what defines each, what properties exist in each, and why those properties are such (based on fundamental laws of physics).
- Complete “Explaining the meaning of calculations” in the Conceptual Reasoning section of the Questions chapter.
- Analyze at least one of the circuits shown in the “Mixed-source circuits” question found in the Quantitative Reasoning section of the Questions chapter.
 - Hint: the key to solving these problems is to identify and judiciously apply Foundational Concepts such as Ohm’s Law, KVL, KCL, properties of series networks, properties of parallel networks, etc. Having a list of these concepts ready is helpful, because if you get stuck trying to figure something out in the circuit you can go through that list one concept at a time to prompt ideas on what to do next.
- Complete “Faulty electric lamp array” 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 contains circuit examples which may serve as practice problems.
- “Problem-solving example: mixed-source circuit” in the Quantitative Reasoning section of the Questions chapter.
- The Gallery chapter of the SPICE Modeling of Resistor 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!
- tshoot circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_004.
file wt_0009

Source text – *Series-Parallel Circuits* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_seriesparallel.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 “Building custom resistance values” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.
- Complete “Four-resistor circuit” in the [Quantitative Reasoning](#) section of the [Questions](#) chapter.
- Run at least one simulation of a loaded voltage divider (Circuit_004) using `tshoot` software, and show the final results.
 - Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series/parallel networks, Kirchhoff’s Laws, etc.)

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

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

Theory Session Expectations:

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

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

Additional resources:

- Sections of the [Case Tutorial](#) chapter contains circuit examples which may serve as practice problems.
- [Modeling a series-parallel circuit using C++](#) section of the [Programming References](#) chapter, complete with a computer program written in the C++ programming language to analyze a series-parallel circuit. You can use the illustrated example as a single worked problem, or by copying and pasting the text of the C++ code into a compiler and modifying some of the component parameters, you may generate your own practice problems (with solutions!) for different component values.
- The [Gallery](#) chapter of the [SPICE Modeling of Resistor 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!
- Using `tshoot` in the “no-fault” mode (`./tshoot -nofault`) to simulate randomized circuits.

[file wt_0096](#)

Theory session 19

Source text – *Bridge Circuits* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Thermistor bridge circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Balancing a resistive bridge” in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a Wheatstone bridge (circuit_005) using `tshoot` software, and show the final results.
 - Base each of your diagnostic tests on the application of some foundational concept of electric circuits (e.g. properties of series/parallel networks, Kirchhoff’s Laws, etc.)

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

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

Theory Session Expectations:

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:

- `tshoot` circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_005.
file wt_0093

Source text – *SPICE Modeling of Resistor Circuits* learning module

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

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

- Read the Introduction chapter and comment on the series resistor circuit example demonstrating how a code listing (called a *netlist*) instructs SPICE how to analyze that circuit.
- Read, outline, and reflect on the Demonstration of NGSPICE interactive mode section of the Using SPICE chapter in its entirety.
- Attempt to run a SPICE simulation on at least one of the example circuits shown in the Demonstration section.
- Read, outline, and reflect on the Idiosyncrasies of SPICE section of the Using SPICE chapter in its entirety.
- Manually compute all voltages and currents and show all your work for the “One DC current source, three resistors” example in the Series resistor circuits section of the Gallery chapter. Then, attempt to run a SPICE simulation on this circuit to compare results.
- Sketch your own circuit, write your own netlist, run SPICE to simulate the circuit, and show that the results computed by SPICE match your own manual predictions. *The purpose of this is to learn how to use SPICE as a tool for providing circuit-analysis results, so you have a means to check your own work when practicing circuit analysis techniques!*

NOTE: examine the questions shown for the next Oral Presentations session (#23), and how every one of the schematic diagrams comes complete with node numbers ready for SPICE simulation! This provides an easy way to create your own practice problems, aiding the construction of netlists where you may insert your own component values and then have SPICE tell you the correct values for voltages and currents in those circuits, to check the accuracy of your own manual calculations.

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_0011

Theory session 21

Source text – *Qualitative Circuit Analysis* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Ladder-diagram switch circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Light sensor” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Measuring a high-resistance signal source” in the Conceptual Reasoning section of the Questions chapter.
- Run at least one simulation of a four-wire resistive sensor (circuit_003) 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.)

A good resource for analytical problem-solving is a list of foundational concepts to reference every time you face a new circuit-analysis problem. If you are ever at a point where you don’t know what to do next, just survey this list to see if any of these concepts might apply:

Check-list of Foundational Concepts

- ☐ Conservation of Energy
- ☐ Conservation of Electric Charge
- ☐ Behavior of sources versus loads
- ☐ Ohm's Law
- ☐ Joule's Law
- ☐ Effects of opens versus shorts
- ☐ Properties of series networks
- ☐ Properties of parallel networks
- ☐ Kirchhoff's Voltage Law
- ☐ Kirchhoff's Current Law

Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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_0097

Theory session 22

Source text – *Elementary Circuit Design* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Read, outline, and reflect on the Ground in electric and electronic circuits section of the Derivations and Technical References chapter.
- Complete “Resistor and terminal blocks with specified voltage polarities” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Resistors with proportional voltage drops” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Potentiometer-based voltage dividers” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Extending the range of a voltmeter” in the Quantitative Reasoning section of the Questions chapter.

A good resource for analytical problem-solving is a list of foundational concepts to reference every time you face a new circuit-analysis problem. If you are ever at a point where you don’t know what to do next, just survey this list to see if any of these concepts might apply:

Check-list of Foundational Concepts

- ☐ Conservation of Energy
- ☐ Conservation of Electric Charge
- ☐ Behavior of sources versus loads
- ☐ Ohm’s Law
- ☐ Joule’s Law
- ☐ Effects of opens versus shorts
- ☐ Properties of series networks
- ☐ Properties of parallel networks
- ☐ Kirchhoff’s Voltage Law
- ☐ Kirchhoff’s Current Law

Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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_0010

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 $1\text{ k}\Omega$ in size and the voltage source is 12 Volts):

```
* Simulating a series-parallel network
v1 2 0 dc 12
r1 1 2 1000
r2 1 3 1000
r3 3 4 1000
r4 4 0 1000
r5 1 4 1000
.op
.end

file wt_0155
```

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:

Check-list of Foundational Concepts

- ☐ Conservation of Energy
- ☐ Conservation of Electric Charge
- ☐ Behavior of sources versus loads
- ☐ Ohm's Law
- ☐ Joule's Law
- ☐ Effects of opens versus shorts
- ☐ Properties of series networks
- ☐ Properties of parallel networks
- ☐ Kirchhoff's Voltage Law
- ☐ Kirchhoff's Current Law

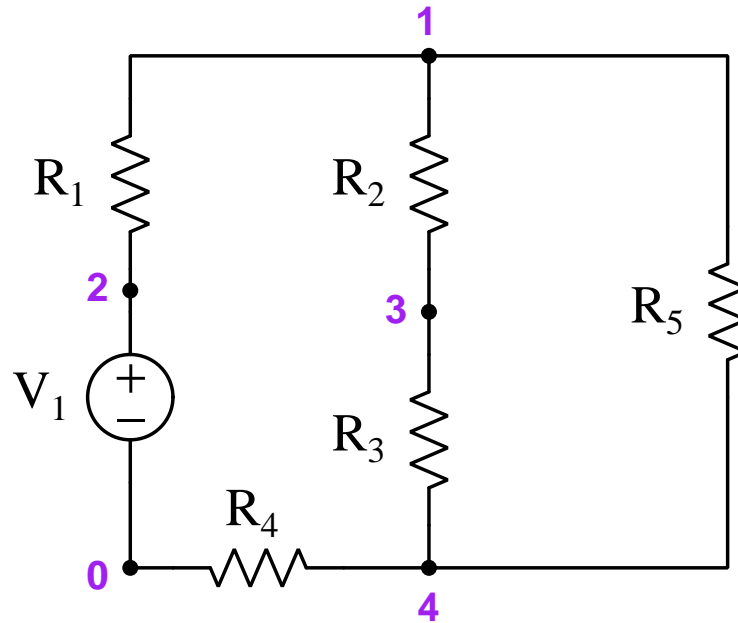
Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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.

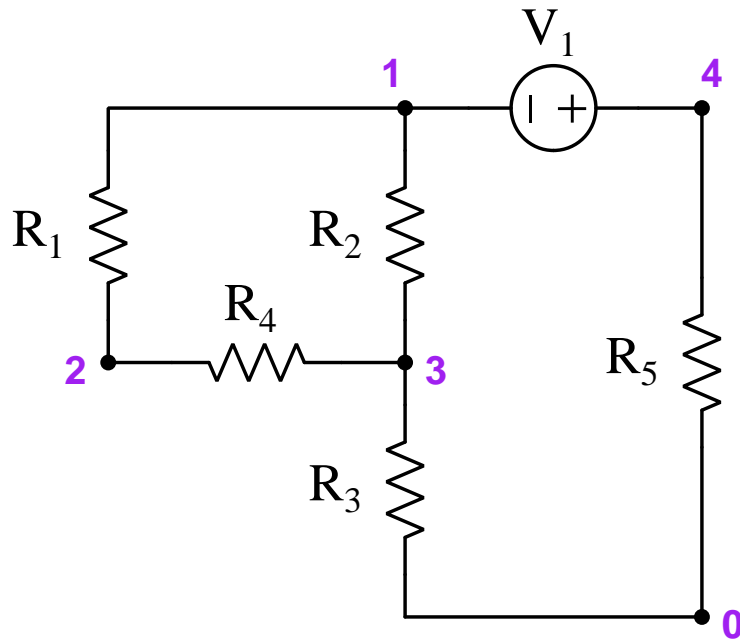
Grading

- ☐ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ☐ [20%] Current magnitude and direction through node 2 (I_2)
- ☐ [20%] All current magnitudes and directions entering and exiting node 4
- ☐ [20%] Voltage magnitude and polarity between nodes 2 and 3 (V_{2-3})
- ☐ [20%] Voltage magnitude and polarity across resistor R_5 (V_{R5})

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.

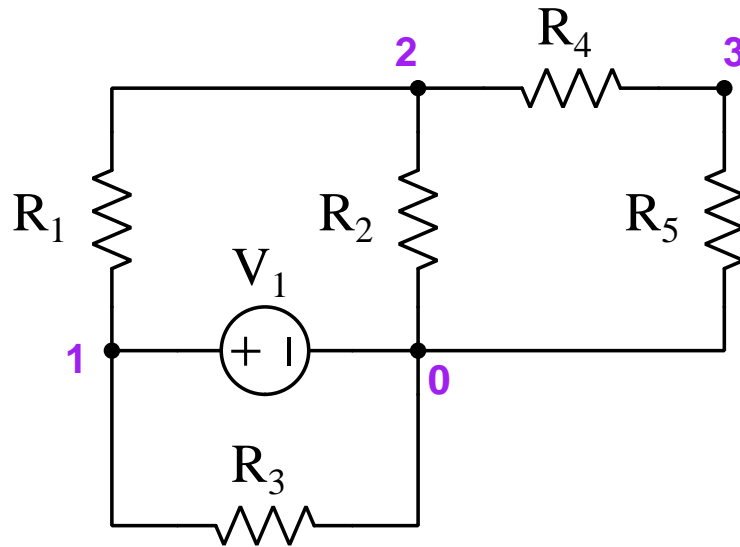
Grading

- ☐ [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

(Component change randomly chosen by instructor):



Note: the instructor will choose one component in this circuit whose value will either increase or decrease. Your task is to determine the qualitative effect (i.e. *increase*, *decrease*, or *remain the same*, in terms of absolute value) on each of the parameters listed below as a result of this component change.

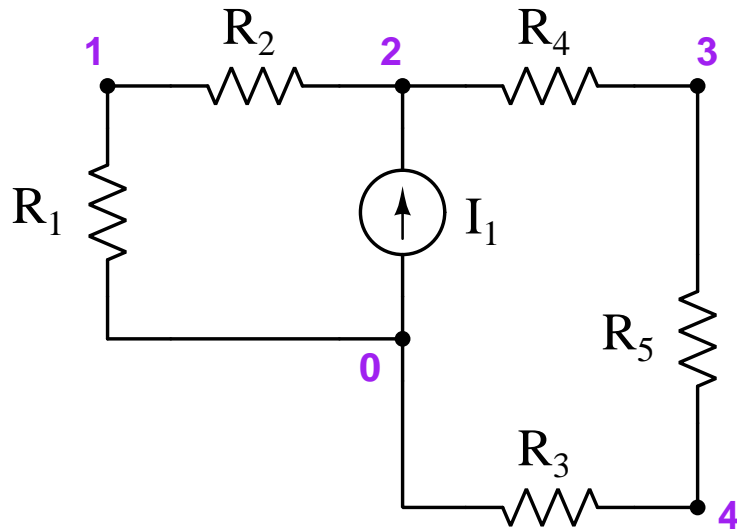
Grading

- ☐ [20%] Current through resistor R_1 (I_{R1})
- ☐ [20%] Current through resistor R_4 (I_{R4})
- ☐ [20%] Voltage across resistor R_5 (V_{R1})
- ☐ [20%] Voltage between nodes 3 and 1
- ☐ [20%] Power dissipated by source V_1 (P_{V1})

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

Problem #4

(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.

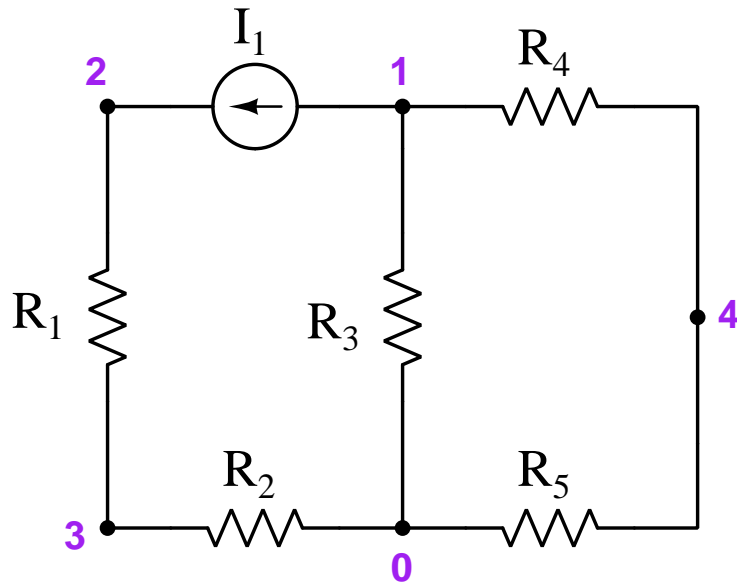
Grading

- ☐ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ☐ [20%] Current magnitude and direction through node 3 (I_3)
- ☐ [20%] All current magnitudes and directions entering and exiting node 0
- ☐ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ☐ [20%] Voltage magnitude and polarity across resistor R_5 (V_{R5})

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

Problem #5

(Component values randomly chosen by instructor):



Note: the instructor will choose one component in this circuit whose value will either increase or decrease. Your task is to determine the qualitative effect (i.e. *increase*, *decrease*, or *remain the same*, in terms of absolute value) on each of the parameters listed below as a result of this component change.

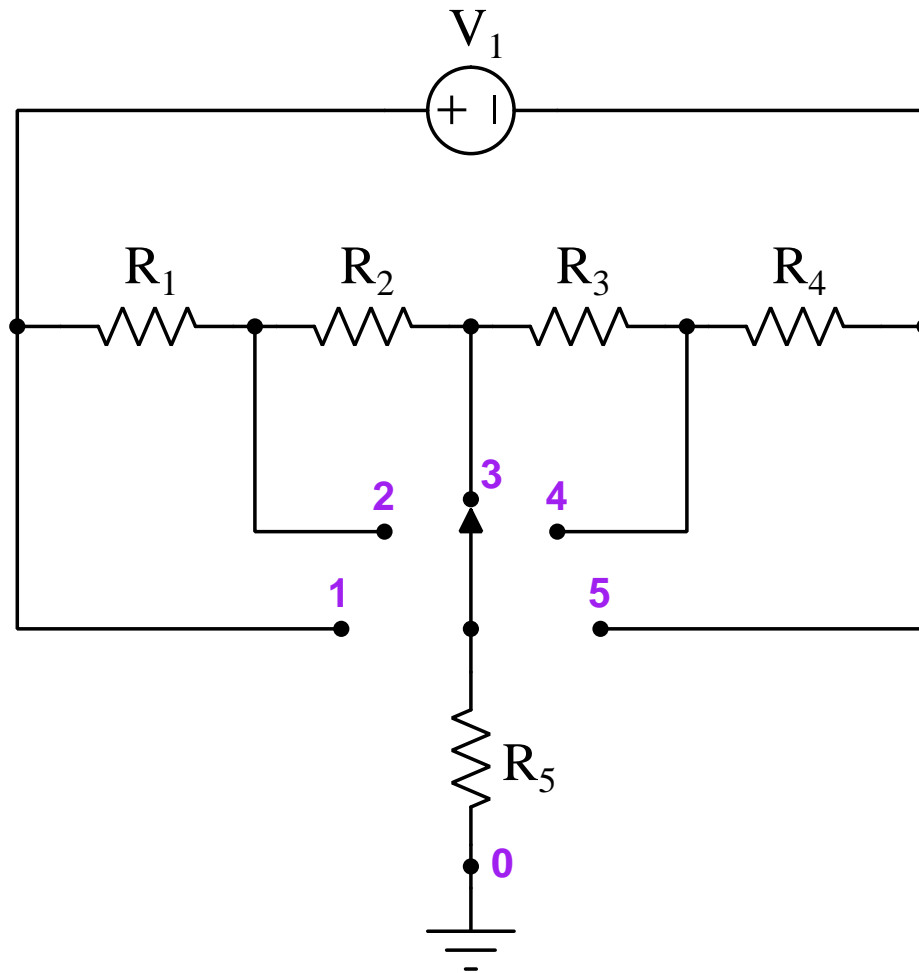
Grading

- ☐ [20%] Current through resistor R_5 (I_{R5})
- ☐ [20%] Current through resistor R_2 (I_{R2})
- ☐ [20%] Voltage across resistor R_3 (V_{R3})
- ☐ [20%] Voltage between nodes 3 and 4
- ☐ [20%] Power dissipated by source I_1 (P_{I1})

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

Problem #6

(Component values and switch position 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. Note also that the value of R_5 is actually irrelevant, since that resistor will carry zero current and exists only to satisfy SPICE (connecting node 0 with one of the non-zero nodes depending on switch position).

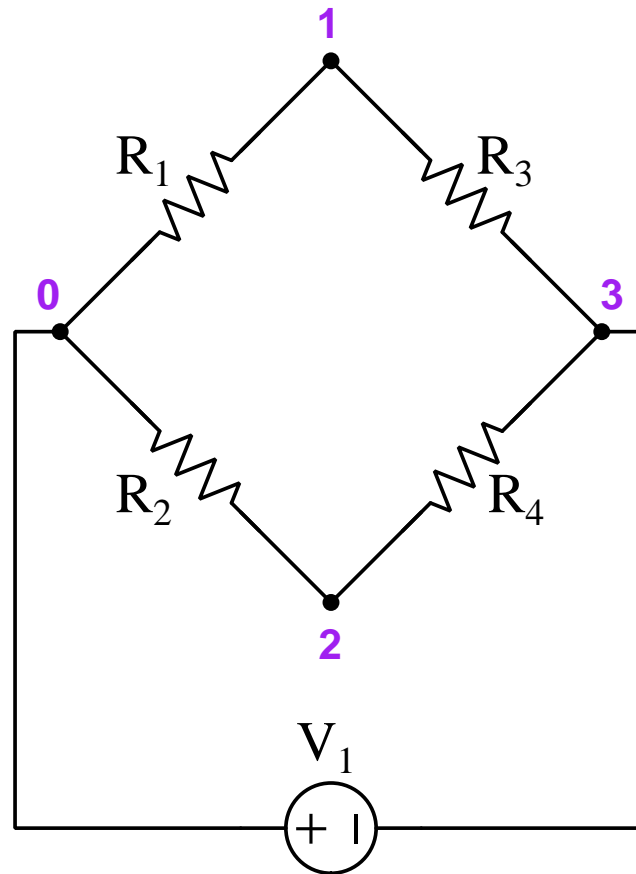
Grading

- ☐ [20%] Voltage magnitude and polarity between node 2 and ground (V_2)
- ☐ [20%] Voltage magnitude and polarity between node 4 and ground (V_4)
- ☐ [20%] Voltage magnitude and polarity between node 5 and ground (V_5)
- ☐ [20%] Voltage magnitude and polarity between node 1 and node 3 (V_{1-3})
- ☐ [20%] Voltage magnitude and polarity between node 5 and node 2 (V_{5-2})

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

Problem #7

(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 1 (I_1)
- ☐ [20%] All current magnitudes and directions entering and exiting node 3
- ☐ [20%] Voltage magnitude and polarity between nodes 1 and 2 (V_{1-2})
- ☐ [20%] Resistance value for resistor R_1 that would balance the bridge (assuming all other resistor values are as given)

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 an unloaded voltage divider network given required voltage and/or current values.
Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks
- (Question #2) Qualitatively predict voltage, current, and power changes in a series 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
- (Question #3) Qualitatively predict voltage, current, and power changes in a 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
- (Question #4) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks
- (Question #5) Determine necessary resistor value to balance a bridge circuit, as well as calculate voltages and currents in that balanced bridge circuit.
Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of bridge networks
- (Question #6) Sketch wire connections necessary to form a complete pictorial circuit diagram equivalent to a given schematic diagram.
Definitions of series and parallel, electrically common points, terminal block function
- (Question #7) Determine possible faults in a voltage divider circuit.
Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, voltage divider circuits
- (Question #8 – REVIEW) Identify voltage polarity given current direction, and current direction given voltage polarity, for both sources and loads. Also, identify sources versus loads given voltage polarity and current direction.
Voltage, current, behavior of sources vs. loads
- (Question #9 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
Voltage, current, behavior of sources vs. loads, multimeter usage

Theory session 25

Source text – *Ideal and Real Sources* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_idealsource.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 Example: dying dry-cell battery under load section of the Case Tutorial chapter, and answer the following questions:
 - Explain how you could conduct your own test of a battery's internal resistance
 - Why was it safe to test the short-circuit current of this battery using an ammeter?
- Complete “Diode modeled as a source” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Ideal current source behavior” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Testing a power supply” 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_0098

Theory session 26

Source text – *Maximum Power Transfer Theorem* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Optimized electrolysis cell” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Series resistance” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Find the mistake(s)” in the Diagnostic Reasoning section of the Questions chapter.

Something you’ll notice in today’s assigned Tutorial reading is a lot of calculation examples for the “cut and try” method of problem solving. Use this as an opportunity for practicing basic circuit analysis by seeing if you can obtain those same calculated results on your own!

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_0099

Theory session 27

Source text – *Superposition Theorem* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “1-5 VDC versus 4-20 mA signaling” in the Conceptual Reasoning section of the Questions chapter.
- Complete “One generator and two batteries” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Actually disabling a source” in the Diagnostic Reasoning section of the Questions chapter.

NOTE: there are many calculations required to apply the Superposition Theorem, and therefore many places one can make mistakes. Here are some proven strategies for success:

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

Theory Session Expectations:

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_0100

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

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Watch the flip-book animation shown in the Animation of Thévenin's Theorem section of the Animations chapter.
 - Try performing the same mathematical calculations to see if you get the same results as shown in the animation for V_{th} and R_{th}
- Complete “Thévenin and Norton equivalents of a single-source network” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Norton equivalent of an electric arc welder” in the Quantitative Reasoning section of the Questions chapter.

NOTE: a common tendency for students encountering any new and challenging topic is to ignore previously-learned and trusted principles when trying to solve problems. This is typical the first time students encounter Thévenin's and Norton's Theorems. The single most important piece of advice I have for you today is to always refer back to those trusted principles such as Ohm's Law, properties of series and parallel networks, KVL and KCL, etc. Usually, when a student “over-thinks” a problem, they're actually just under-utilizing foundational concepts they already know well!

The habit of many students prior to college is to ignore or discard any information learned previously because their prior educational experience tells them they won't need any of that knowledge later. This is absolutely untrue in the hard sciences where practically every new concept builds on previous concepts! In the bright side, know that nothing you're every studying in this course is ever wasted effort!

Theory Session Expectations:

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

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

Additional resources:

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

file wt_0101

Theory session 29

Source text – *Electric and Magnetic Fields* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Electric versus magnetic fields
 - Electromagnetism
 - The right-hand rule
 - Electric motors
 - Electromagnetic induction
 - Lenz's Law
- Complete “An energized solenoid” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Induced current directions” in the Conceptual Reasoning section of the Questions chapter.
- Build an electromagnet out of commonly available materials (e.g. steel bolt, insulated wire) and demonstrate how to create a magnetic field using electricity
- Take that same electromagnet coil you constructed and demonstrate how to create electricity using the magnetic field from a permanent magnet

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_0102

Theory session 30

Source text – *Electromechanical relays* learning module

URL – https://ibiblio.org/kuphaldt/socratic/model/mod_relay.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 relay?
 - Contact arrangements
 - Relay ratings
 - Latching and sequencing relays
 - Solid-state relays
- Complete “Sketching connections for a dual lamp circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “5 Volt relay powered by a 24 Volt source” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Find the mistake” in the Diagnostic 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_0103

Theory session 31

Source text – *Capacitance and Inductance* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
- Complete “Safe de-energization” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Capacitors and inductors compared against batteries” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Capacitor and inductor fault pathology” 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_0104

Theory session 32

Source text – *Capacitors and Capacitive Circuits*

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Show your attempts to calculate the same quantities shown in the Tutorial’s examples:
 - Annotate the schematic diagrams
 - Plot voltage and current curves showing the shapes of each
 - Show the calculations you did, and whether or not your answers matched the text’s
 - *The purpose of this is to practice a highly effective technical reading and study habit, as well as to self-check your understanding of the concepts!*
- Complete “Capacitor charging circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “SPICE analysis of an energizing capacitor” in the Quantitative Reasoning section of the Questions chapter.
- Complete “SPICE analysis of a de-energizing capacitor” in the Quantitative Reasoning section of the Questions chapter.

NOTE: here are some common challenges for students learning these concepts:

- Confusing the e^x (exponential) function of your calculator with the EE (power-of-ten) function
- Improper entry of values into your calculator
- Failure to carefully reason from basic principles of energy storage for capacitors (i.e. that capacitors store energy in electric fields, and these fields manifest as voltage, therefore a capacitor’s voltage cannot vary without energy being absorbed or released by it)

Theory Session Expectations:

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

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

Additional resources:

- Modeling inverse exponential growth and decay section of the Derivations and Technical References chapter.
- Modeling an energizing capacitor using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions!
- The Gallery chapter of the SPICE Modeling of Inductive and Capacitive 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_0012

Theory session 33

Source text – *Inductors and Inductive Circuits*

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Show your attempts to calculate the same quantities shown in the Tutorial’s examples:
 - Annotate the schematic diagrams
 - Plot voltage and current curves showing the shapes of each
 - Show the calculations you did, and whether or not your answers matched the text’s
 - *The purpose of this is to practice a highly effective technical reading and study habit, as well as to self-check your understanding of the concepts!*
- Complete “Inductor charging circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Toroidal inductor wire turns” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Tabulating inductor charging” in the Quantitative Reasoning section of the Questions chapter.

NOTE: here are some common challenges for students learning these concepts:

- Confusing the e^x (exponential) function of your calculator with the EE (power-of-ten) function
- Improper entry of values into your calculator
- Failure to carefully reason from basic principles of energy storage for inductors (i.e. that inductors store energy in magnetic fields, and these fields manifest as current, therefore an inductor’s current cannot vary without energy being absorbed or released by it)

Theory Session Expectations:

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

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

Additional resources:

- Modeling inverse exponential growth and decay section of the Derivations and Technical References chapter.
- Modeling an energizing inductor using C++ section of the Programming References chapter. By copying and pasting the text of the C++ code into a compiler, and modifying some of the component parameters, you may generate your own practice problems and solutions!
- The Gallery chapter of the SPICE Modeling of Inductive and Capacitive 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_0013

Source text – *SPICE Modeling of Inductive and Capacitive Circuits* learning moduleURL – https://ibiblio.org/kuphaldt/socratic/model/mod_spice_lc.pdf

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

- Read and reflect on the following sections of the [Gallery](#) chapter, taking note on how SPICE is used to simulate capacitive and inductive circuits:
 - [Resistor-capacitor DC circuits](#)
 - [555 timer circuits](#)
 - [Resistor-inductor DC circuits](#)
- Now, do the following:
 - Run one of these simulations using SPICE, verifying you get the same results as shown in the text
 - Calculate capacitor voltage and capacitor current for any of the circuits shown, at a point in time computed by SPICE so you may check the accuracy of your work
 - Calculate inductor voltage and inductor current for any of the circuits shown, at a point in time computed by SPICE so you may check the accuracy of your work
 - Explain why $t_{charge} = 0.693(R_1 + R_2)C$ and $t_{discharge} = 0.693R_2C$ for a 555 timer operating in “classic” astable mode (hint: it will be easier to prove the discharge case first!)
 - Explain how Thévenin’s Theorem is useful for analyzing at least one of these circuits

Suggestions for solving time-delay problems such as this include:

- Always sketch a qualitative graph showing the variable’s progression over time, before attempting to calculate values. This forces you to think conceptually, which is key to correctly applying mathematical solutions to any physical system.
- To correctly identify where a capacitor or inductor’s value(s) will start and finish over time, always think in terms of energy conservation and the means by which each of those components stores energy.
 - A capacitor’s voltage resists change because energy must flow into or out of the capacitor in order for its voltage to vary, given that capacitor energy is a function of its electric field, which in turn is a function of voltage ($E_C = \frac{1}{2}CV^2$). Energy transfer represents *work*, and this takes time.
 - An inductor’s current resists change because energy must flow into or out of the inductor in order for its current to vary, given that inductor energy is a function of its magnetic field, which in turn is a function of current ($E_L = \frac{1}{2}LI^2$). Energy transfer represents *work*, and this takes time.
- The inverse-exponential formulae do not directly provide voltage or current values, but merely tell you the *fraction* of the voltage or current in question in terms of its initial and final values. For example, after 5 seconds of time in a circuit with a 10-second τ value, $e^{-\frac{5}{10}} = 0.60653$ tells us any decreasing voltage or current has decayed to 60.653% of the difference between its initial and final values. After 7 seconds of time in a circuit with a 10-second τ value, $1 - e^{-\frac{7}{10}} = 0.50341$ tells us any increasing voltage or current has grown to 50.341% of the difference between its initial and final values.

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_0249](#)

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 netlists (one for charging, one for discharging, assuming all resistors are $1\text{ k}\Omega$ in size, the capacitor is $220\text{ }\mu\text{F}$, and the voltage source is 12 Volts):

```
* Simulating a charging capacitor
v1 0 2 dc 12
r1 1 0 1000
r2 3 0 1000
rswitch 1 2 1e-6
c1 3 1 220e-6 ic=0
.tran 0.05 1 uic
.end

* Simulating a discharging capacitor
v1 0 2 dc 12
r1 1 0 1000
r2 3 0 1000
rswitch 1 2 999e6
c1 3 1 220e-6 ic=12
.tran 0.05 1 uic
.end
```

After loading either of these netlists into NGSPICE and running the simulation (by typing **run** in the NGSPICE command line), we may either plot a graph of the capacitor's voltage over time with the command **plot v(3,1)** or print a list of numerical values for the same with the command **print v(3,1)**. In either case, the **plot** or **print** command is instructed to display the voltage between nodes 3 and 1, which are the two nodes of the capacitor's terminals.

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:

Check-list of Foundational Concepts

- ☐ Conservation of Energy
- ☐ Conservation of Electric Charge
- ☐ Behavior of sources versus loads
- ☐ Ohm's Law
- ☐ Joule's Law
- ☐ Effects of opens versus shorts
- ☐ Properties of series networks
- ☐ Properties of parallel networks
- ☐ Kirchhoff's Voltage Law
- ☐ Kirchhoff's Current Law
- ☐ Maximum Power Transfer Theorem
- ☐ Superposition Theorem
- ☐ Thevenin's and Norton's Theorems
- ☐ Electric fields and capacitance
- ☐ Magnetic fields and inductance
- ☐ Inverse-exponential growth/decay

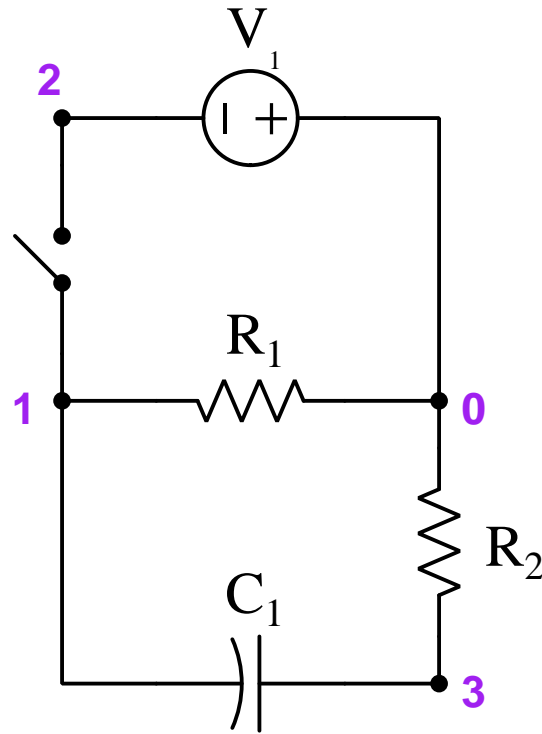
Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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

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:



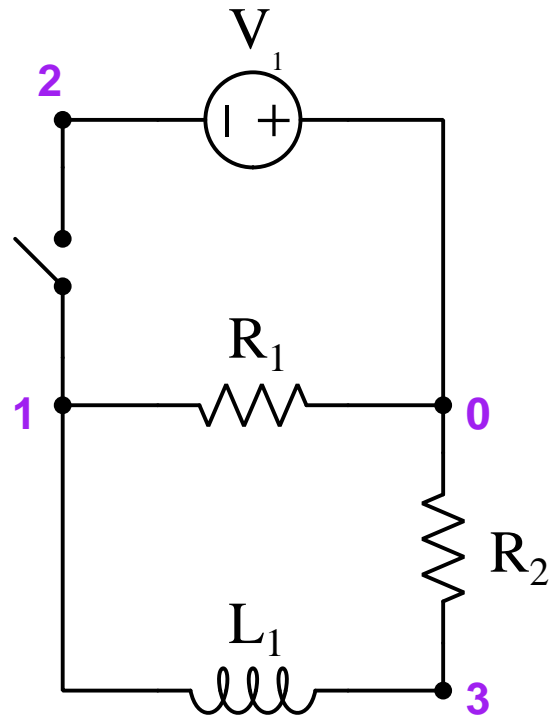
Grading

- ☐ [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 #2

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:



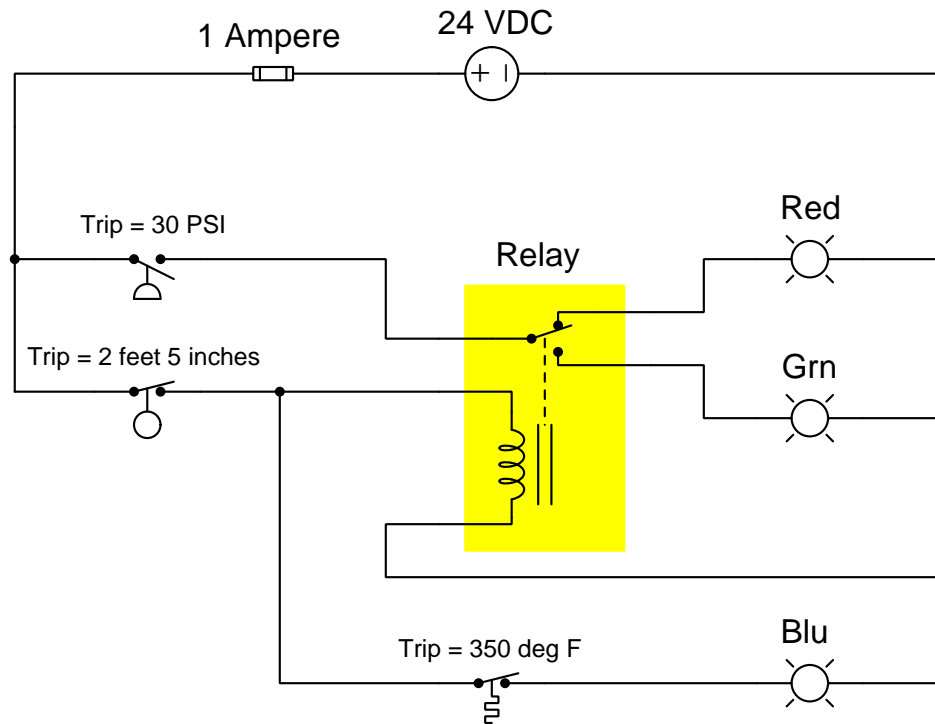
Grading

- ☐ [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 #3

Identify component statuses both before and after component ____ fails (*open/shorted*), assuming the specified process conditions:



- Pressure = ____ PSI
- Level = ____ feet
- Temperature = ____ degrees F

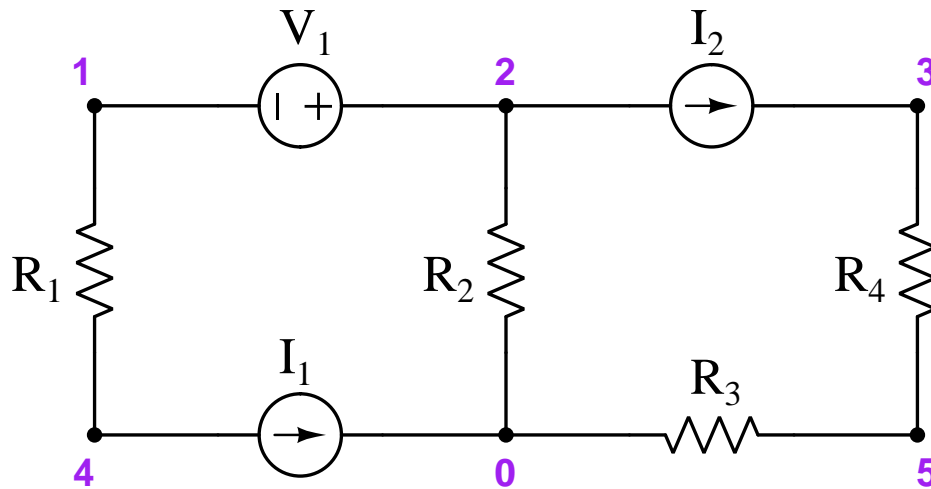
Grading

- ☐ [10%] Red lamp status (*on/off*) before the fault occurs =
- ☐ [10%] Red lamp status (*on/off*) after the fault occurs =
- ☐ [10%] Green lamp status (*on/off*) before the fault occurs =
- ☐ [10%] Green lamp status (*on/off*) after the fault occurs =
- ☐ [10%] Blue lamp status (*on/off*) before the fault occurs =
- ☐ [10%] Blue lamp status (*on/off*) after the fault occurs =
- ☐ [10%] Relay coil status (*energized/de-energized*) before the fault occurs =
- ☐ [10%] Relay coil status (*energized/de-energized*) after the fault occurs =
- ☐ [20%] Source current change (*increase/decrease/same as before the fault*) =

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

Problem #4

(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.

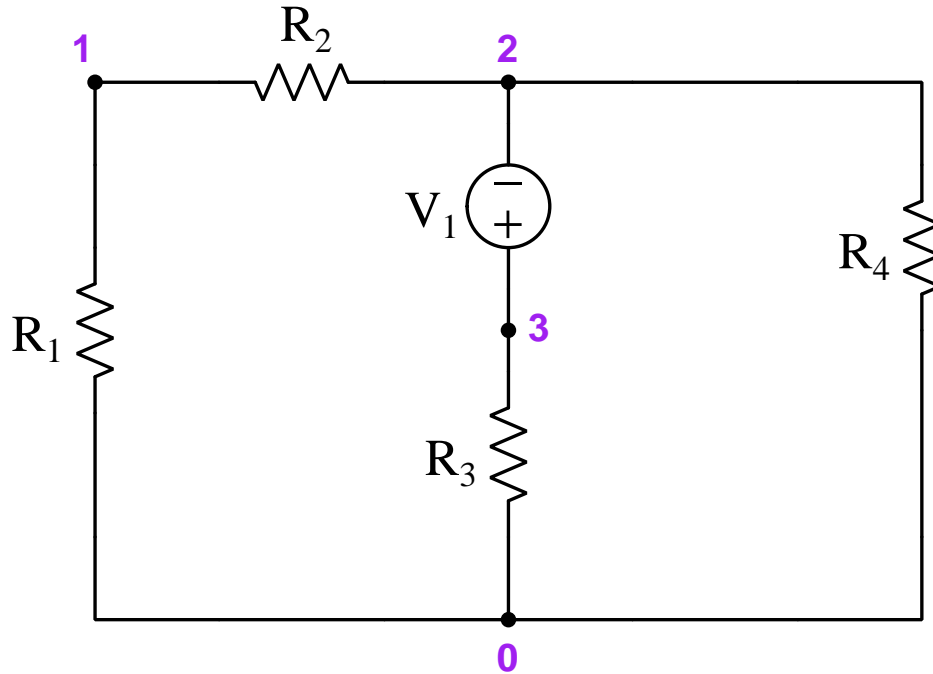
Grading

- ☐ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ☐ [20%] Current magnitude and direction through node 5 (I_5)
- ☐ [20%] All current magnitudes and directions entering and exiting node 2
- ☐ [20%] Voltage magnitude and polarity between nodes 1 and 3 (V_{1-3})
- ☐ [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

Thévenize this circuit, assuming resistor ____ is the load. Component values will be randomly chosen by instructor:

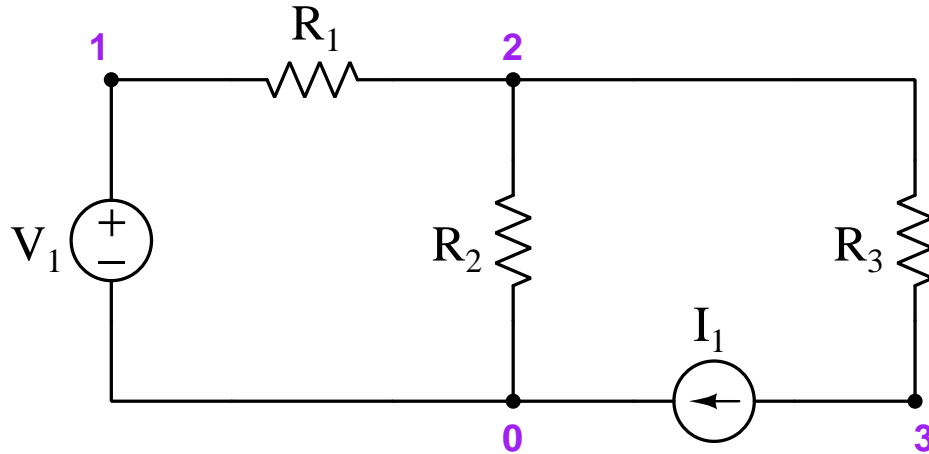
**Grading**

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

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

Problem #6

Apply the Superposition Theorem to the following circuit, with 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.

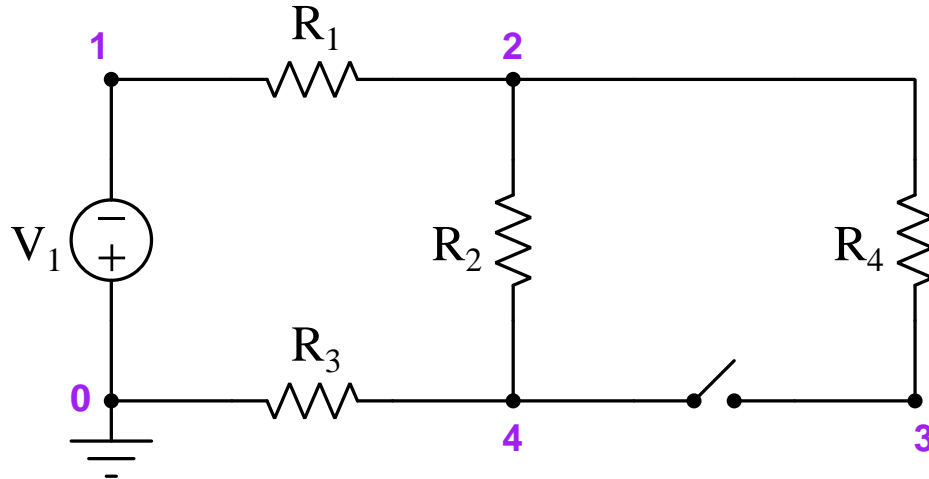
Grading

- ☐ [20%] All voltage magnitudes and polarities with just source V_1 active
- ☐ [20%] All voltage magnitudes and polarities with just source I_1 active
- ☐ [20%] Current magnitude and direction through resistor R_1 (I_{R1})
- ☐ [20%] Current magnitude and direction through resistor R_2 (I_{R2})
- ☐ [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 #7

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

**Grading**

- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor R_1 (I_{R1})
- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor R_2 (I_{R2})
- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor R_3 (I_{R3})
- ☐ [20%] Voltage magnitude variation (increase/decrease/same) between nodes 2 and 3 (V_{2-3})
- ☐ [20%] Voltage magnitude variation (increase/decrease/same) across resistor R_1 (V_{R1})

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

Theory session 36

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

- (Question #1) Calculate voltages, currents, and/or times for a resistor-capacitor circuit.
Properties of series and parallel networks, behaviors of sources and loads, capacitor behavior, inverse exponential calculations, qualitative determination of voltages and currents over time for RC networks
- (Question #2) 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, qualitative determination of voltages and currents over time for LR networks
- (Question #3) Calculate voltages, currents, and/or power dissipations in a circuit containing multiple sources.
Properties of series and parallel networks, behaviors of sources and loads, Ohm's Law, Joule's Law, Kirchhoff's Laws, Maximum Power Transfer Theorem, Superposition Theorem, Thévenin's Theorem, Norton's Theorem
- (Question #4) Design and sketch a circuit exhibiting a specified inverse-exponential rise or decay for either voltage or current.
Properties of series and parallel networks, capacitor behavior, inductor behavior, inverse exponential calculations, qualitative determination of voltages and currents over time for RC and LR networks
- (Question #5) Determine possible faults in an RC or LR time-delay circuit.
Voltage, current, effects of opens vs. shorts, capacitor behavior, inductor behavior, behavior of sources vs. loads, qualitative determination of voltages and currents over time for RC and LR networks, electromechanical relay operation, "normal" switch contact states
- (Question #6 – REVIEW) Identify the presence or absence of voltage between specified pairs of points in a single-source, single-load circuit.
Electrically common points, electrically distinct points, voltage, tracing current in a circuit, sources versus loads
- (Question #7 – REVIEW) Calculate voltage, current, resistance, and/or power in a simple circuit given necessary as well as extraneous parameters.
Ohm's Law, Joule's Law, resistor 4-band color codes
- (Question #8 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
Voltage, current, behavior of sources vs. loads, multimeter usage
- (Question #9 – REVIEW) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

Theory session 37

Source text – *Conductors, Insulators, and Semiconductors* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
 - Explain what one of the more complex illustrations shown in the Tutorial means, connecting words in the text with the graphic image(s). *The purpose of this is to practice a highly effective technical reading and study habit.*
- Complete “Solar panel output” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Light-emitting diodes” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Predicting diode current” 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:

- Experiment with measuring solar panel output voltage and output current on the lab’s miniature DC power grid, drawing blinds in front of the panels to modulate the incident sunlight falling on the panels.
- Experiment with measuring the forward voltage drop of different LEDs all carrying the exact same amount of current.

file wt_0156

Theory session 38

Source text – *PN Junctions and Diodes* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Watch the flip-book animation shown in the Animation of a forward-biased PN diode junction section of the Animations chapter.
- Complete “Motor-effect eliminator” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Voltages and currents in simple diode circuits” in the Quantitative Reasoning section of the Questions chapter.
- Complete “LED resistor sizing” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faults in a diode-resistor network” in the Diagnostic Reasoning section of the Questions chapter.
- Locate a manufacturer’s datasheet for a diode and comment on the ratings and graphs contained therein.
Note: use the EETREF collection of documents available on all the classroom PCs to avoid having to search through pages of junk on the internet!

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 a forward-biased PN diode junction section of the Animations chapter.
file wt_0015

Theory session 39

Source text – *Bipolar Junction Transistors* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
- Complete “Controlling and controlled currents” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Proper BJT types” in the Conceptual Reasoning section of the Questions chapter.
- Complete “BJT circuit calculations” in the Quantitative Reasoning section of the Questions chapter.

Note: transistors are complex devices, and challenging to understand at an internal level. If you find yourself confused by the Full Tutorial presentation of this subject, try reading the Simplified Tutorial to see if that clarifies matters. This is good advice in general for any module containing both Full and Simplified Tutorial chapters.

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 Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

file wt_0076

Source text – *Bipolar Junction Transistors* learning module

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

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

- Read, outline, and reflect on the John Bardeen’s and Walter Brattain’s Transistor Patent section of the Historical References chapter, and answer the following questions:
 - What do you suppose the authors mean by the word *translate*?
 - Identify some of the lesser-used semiconducting materials mentioned by the authors.
 - What type of semiconductor (N- or P-type) is the block of semiconducting material made of in this transistor, and how can we tell?
 - What is the significance of matching the impedance (i.e. resistance) of a load to the internal resistance of the collector terminal in the transistor amplifier circuit?
 - Examining the construction of this prototype transistor, why do you think the “base” terminal is so named?
 - What does the term *gain* mean in the context of this device?
- Complete “Common-emitter behavior” in the Conceptual Reasoning section of the Questions chapter.
- Complete “DC bias calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Faults in test circuit” in the Diagnostic Reasoning section of the Questions chapter.

Today’s reading assignment is fairly advanced, as the author(s) were writing to readers who were expected to be scientists and engineers. It’s to be expected that *some* of what was written in this text is well beyond what you have studied about this subject, and may not have made much sense to you.

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. reading advanced texts) that might be beneficial to your self-directed learning in the future? What does today’s experience tell you about what you’re able to understand from a presentation intended for an advanced technical audience? 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:

- The Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
 - The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
- file wt_0077

Theory session 41

Source text – *Field-Effect Transistors* learning module

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

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

- Read, outline, and reflect on the Full Tutorial chapter in its entirety.
 - Translate the text’s descriptions of how the applied gate-substrate voltage affects the “channel” inside the MOSFET to your own annotations of N-channel and P-channel MOSFET devices. In other words, annotate what the text describes! This is a very useful active reading strategy in general for technical concepts.
- Complete “Identifying MOSFET states” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Sketching MOSFET switch circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Dim lamp” in the Diagnostic Reasoning section of the Questions chapter.

Note: one of the more difficult concepts for students to master in this section surrounds the conditions necessary to turn on each type of FET. You may find the Simplified Tutorial in this module helpful in this regard. Generally speaking, if you’ve been assigned to read the Full Tutorial of any module and find yourself confused on any points, feel free to peruse the Simplified Tutorial as an additional resource. Since the E-type MOSFET is the most popular of these field-effect transistors, concentrate on it the most!

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 Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!
file wt_0078

Source text – *Field-Effect Transistors* learning module

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

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

- Examine and reflect on the Example: JFET biasing section of the Case Tutorial chapter, and answer the following questions:
 - In general, what condition(s) is/are necessary to turn off a JFET?
 - In general, what condition(s) is/are necessary to turn on a JFET?
- Examine and reflect on the Example: E-type MOSFET biasing section of the Case Tutorial chapter, and answer the following questions:
 - In general, what condition(s) is/are necessary to turn off an E-type MOSFET?
 - In general, what condition(s) is/are necessary to turn on an E-type MOSFET?
- Complete “Identifying MOSFET stimuli” in the Conceptual Reasoning section of the Questions chapter.
- Complete “ESD test jig” in the Quantitative Reasoning section of the Questions chapter.
- Locate a datasheet for a power MOSFET transistor and identify some of its relevant performance parameters (e.g. $V_{GS(on)}$).

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 Simplified Tutorial chapter is a good reference on these concepts, presented with no extraneous information whatsoever.
- The Gallery chapter of the SPICE Modeling of Semiconductor Circuits learning module contains circuit examples complete with computer-generated analyses useful as practice problems. Using SPICE, you may modify these simulations for the purpose of generating your own practice problems and solutions!

file wt_0079

Theory session 43

Source text – *Transistor switching circuits* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - BJT and FET review
 - Transistor saturation
 - High-side and low-side switching
 - BJT switching
 - MOSFET switching
- Complete “Transistor summary” in the Conceptual Reasoning section of the Questions chapter.
- Complete “BJT switching circuit configurations” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “MOSFET switching circuit configurations” 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_0019

Source text – *Transistor switching circuits* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Switching inductive loads
 - Paralleling transistors
 - H-bridge networks
- Locate the datasheet for a high-current BJT and answer the following questions:
 - What is its maximum collector current?
 - What is its maximum power dissipation?
 - How much current gain (β , or h_{FE}) does it typically offer?
 - How much voltage can it withstand from collector to emitter when turned off?
 - How much voltage will it drop from collector to emitter when saturated?
- Locate the datasheet for a high-current MOSFET and answer the following questions:
 - What is its maximum drain current?
 - What is its maximum power dissipation?
 - How much gate-source voltage is necessary to turn it on?
 - How much voltage can it withstand from drain to source when turned off?
 - How much resistance will it exhibit from drain to source when saturated?
- Complete “Darlington pair current calculations” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Calculations in TIP31C transistor circuit” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Calculations in IRF9520 transistor circuit” 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_0020

Theory session 45

Source text – *Transistor switching circuits* learning module

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

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

- Examine any of the low-side or high-side example circuits shown in the Case Tutorial chapter, and answer the following questions:
 - Will the transistor be saturated when turned on? How exactly can we tell?
 - How is the transistor's on-state power dissipation calculated?
- Complete “Identifying BJT states” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Saturated versus unsaturated BJT switching circuits” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Reliable and unreliable lamp control circuits” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “Fixing a mis-designed motor control 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.

file wt_0250

Theory session 46

Source text – *Thyristors* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “SCR versus TRIAC circuits” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Voltage rate-of-change from oscillographs” in the Quantitative Reasoning section of the Questions chapter.
- Complete “2N6403 specifications” in the Quantitative Reasoning section of the Questions chapter.
- Complete “2N6344 specifications” 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_0021

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:

Check-list of Foundational Concepts

- | | |
|---|--|
| <input type="checkbox"/> Conservation of Energy | <input type="checkbox"/> Conduction in semiconductors |
| <input type="checkbox"/> Conservation of Electric Charge | <input type="checkbox"/> Behavior of PN junctions |
| <input type="checkbox"/> Behavior of sources versus loads | <input type="checkbox"/> Behavior of BJTs |
| <input type="checkbox"/> Ohm's Law | <input type="checkbox"/> Behavior of FETs |
| <input type="checkbox"/> Joule's Law | <input type="checkbox"/> Sourcing versus sinking current |
| <input type="checkbox"/> Effects of opens versus shorts | <input type="checkbox"/> Behavior of thyristors |
| <input type="checkbox"/> Properties of series networks | |
| <input type="checkbox"/> Properties of parallel networks | |
| <input type="checkbox"/> Kirchhoff's Voltage Law | |
| <input type="checkbox"/> Kirchhoff's Current Law | |
| <input type="checkbox"/> Maximum Power Transfer Theorem | |
| <input type="checkbox"/> Superposition Theorem | |
| <input type="checkbox"/> Thevenin's and Norton's Theorems | |
| <input type="checkbox"/> Electric fields and capacitance | |
| <input type="checkbox"/> Magnetic fields and inductance | |
| <input type="checkbox"/> Inverse-exponential growth/decay | |

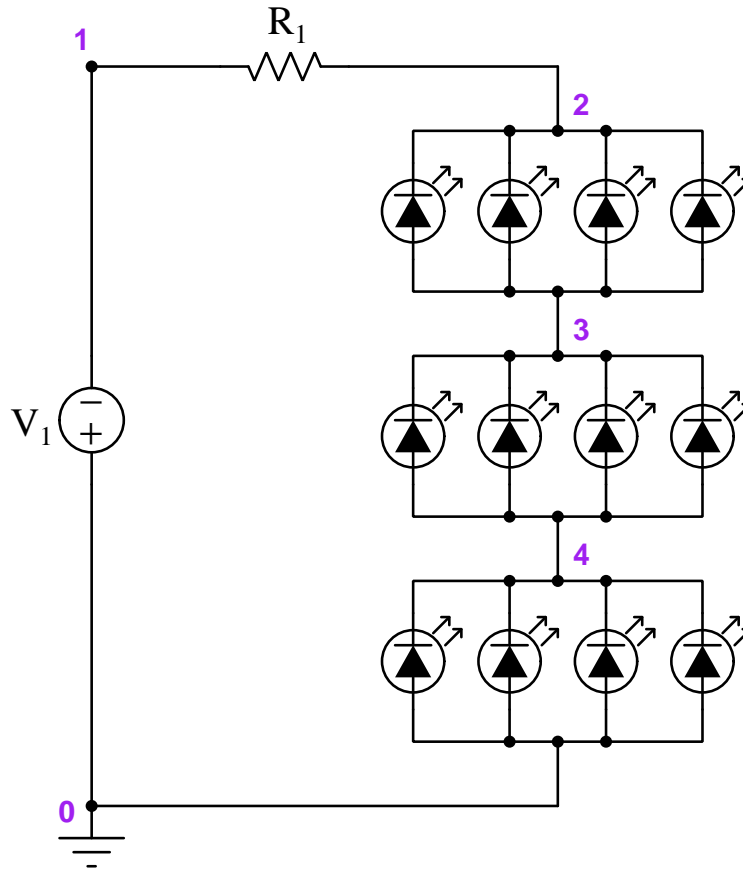
Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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

(Voltage source value and V_F/I_F values for the identical LEDs randomly chosen by the instructor):

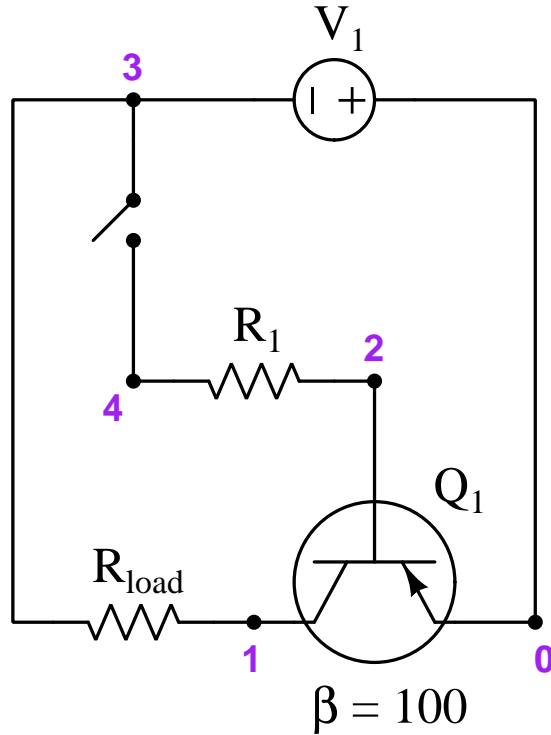
**Grading**

- ☐ [20%] Necessary resistance value for R_1 to limit LED current
- ☐ [20%] Power dissipation of resistor R_1 (P_{R1})
- ☐ [20%] Power output by source V_1 (P_{V1})
- ☐ [20%] Voltage magnitude and polarity between nodes 1 and 4 (V_{1-4})
- ☐ [20%] All current magnitudes and directions entering and exiting node 2

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

Problem #2

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

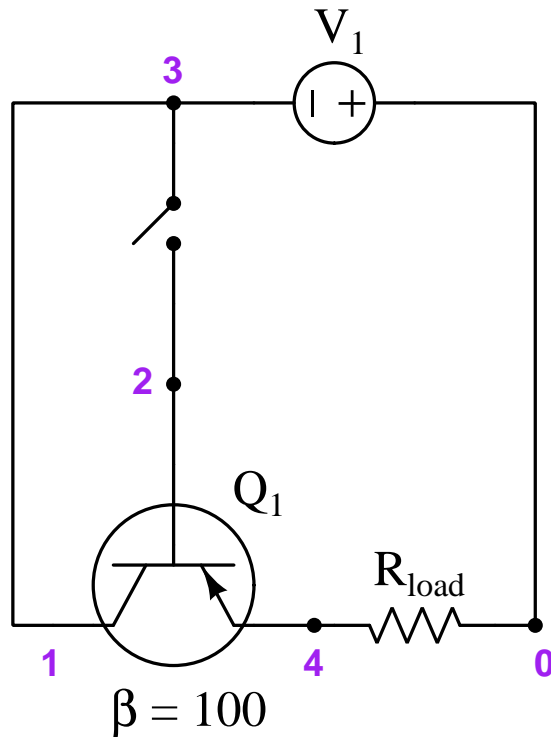
**Grading**

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

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

Problem #3

(V_1 and R_{load} component values randomly chosen by instructor):

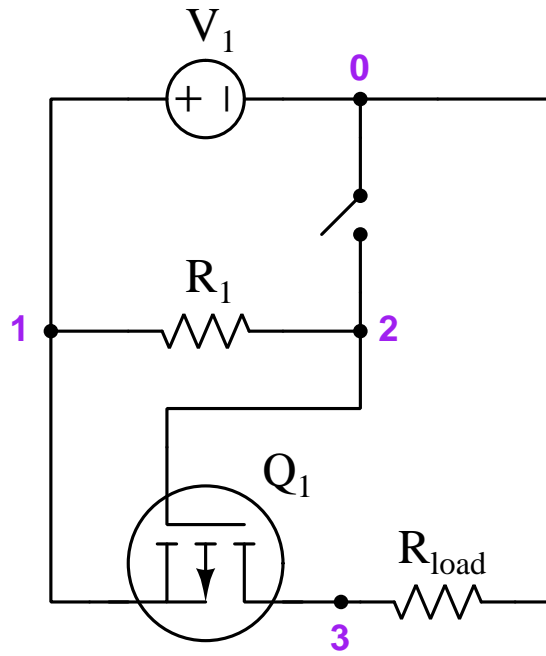
**Grading**

- ☐ [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%] All current magnitudes and directions entering and exiting node 3

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

Problem #4

(Component values randomly chosen by instructor, including $R_{DS(on)}$ parameter of transistor Q_1):

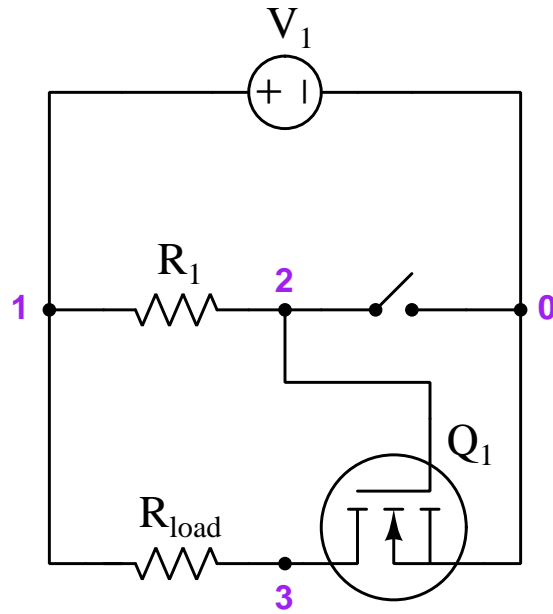
**Grading**

- ☐ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ☐ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch closed
- ☐ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch open
- ☐ [20%] Power dissipated by transistor Q_1 when switch closed
- ☐ [20%] All current magnitudes and directions entering and exiting node 2 when switch closed

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

Problem #5

(Component values randomly chosen by instructor, including $R_{DS(on)}$ parameter of transistor Q_1):

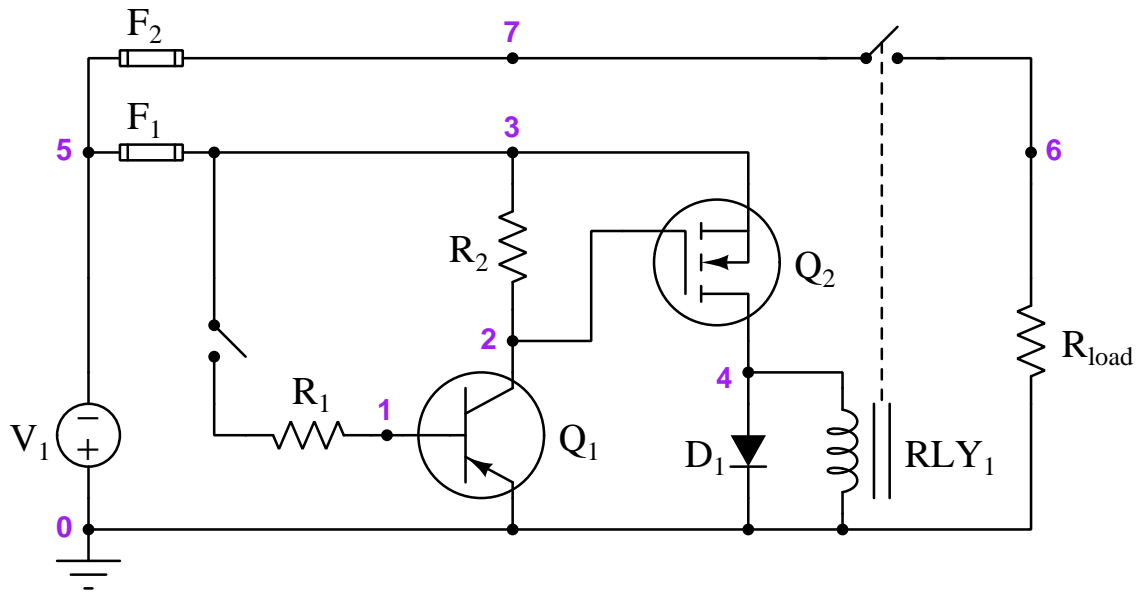
**Grading**

- ☐ [20%] Current magnitude and direction through load resistor (I_{load}) when switch closed
- ☐ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch closed
- ☐ [20%] Voltage magnitude and polarity between drain and source (V_{DS}) when switch open
- ☐ [20%] Power dissipated by transistor Q_1 when switch closed
- ☐ [20%] All current magnitudes and directions entering and exiting node 2

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

Problem #6

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

**Grading**

- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor R_1 (I_{R1})
- ☐ [20%] Current magnitude variation (increase/decrease/same) through resistor R_2 (I_{R2})
- ☐ [20%] Current magnitude variation (increase/decrease/same) through load (I_{load})
- ☐ [20%] Voltage magnitude variation (increase/decrease/same) between node 4 and ground (V_4)
- ☐ [20%] Status (on/off) of transistor Q_2

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

Problem #7

Sketch a circuit using a transistor (either *PNP* or *NPN BJT* or *N-channel* or *P-channel MOSFET*, chosen by instructor) to control the energization of a ____ Ohm load from a ____ Volt power source. The instructor will also randomly assign relevant transistor parameters (e.g. β for a BJT, V_{Th} and $R_{DS(on)}$ for a MOSFET).

Grading

- ☐ [10%] Transistor type matches the instructor's selection
- ☐ [20%] Transistor receives proper polarity of control stimulus
- ☐ [20%] Transistor conducts load current in the correct direction
- ☐ [20%] Calculate power dissipation of transistor with load energized
- ☐ [20%] Calculate voltage dropped across the transistor's load-bearing terminals while load is energized
- ☐ [10%] Transistor will operate in saturated mode when load is energized

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) Design and sketch a circuit using a BJT to switch DC power to a load.
BJT behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks
- (Question #2) Design and sketch a circuit using a FET to switch DC power to a load.
FET behavior, behavior of sources and loads, Kirchhoff's Laws, properties of series and parallel networks
- (Question #3) 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 #4) Select appropriate component values (e.g. resistor resistance) for a semiconductor switching circuit.
Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior, thyristor behavior
- (Question #5) Determine possible faults in a BJT or FET or thyristor switching circuit.
Properties of series and parallel networks, effects of opens vs. shorts, behavior of sources and loads, BJT behavior, FET behavior, thyristor behavior
- (Question #6 – REVIEW) Determine the nominal, low, and high resistance values for four-band resistors given their band colors.
Resistor 4-band color codes, percentage calculations, tolerance
- (Question #7 – REVIEW) Design and sketch an unloaded voltage divider network given required voltage and/or current values.
Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series networks
- (Question #8 – REVIEW) Sketch proper multimeter connections to measure voltage, current, or resistance in a pictorial diagram of a circuit.
Voltage, current, behavior of sources vs. loads, multimeter usage
- (Question #9 – REVIEW) Calculate voltages, currents, resistances, and/or power dissipations in a series-parallel resistor circuit.
Properties of series and parallel networks, Ohm's Law, Kirchhoff's Voltage Law, Kirchhoff's Current Law, effects of opens vs. shorts, behavior of sources and loads, reduction of series-parallel networks into equivalent networks

Theory session 49

Source text – *Basic Principles of Digital* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Read, outline, and reflect on the Punched paper tape section of the Historical References chapter.
- Complete “Logic levels in a simple transistor circuit” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Using Python to evaluate basic logic expressions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Effects of faults in simple digital 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.

file wt_0025

Source text – *Relay Ladder Logic* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Complete “Active reading exercise: motor control circuit diagram” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Truth table for a relay circuit” in the Quantitative Reasoning section of the Questions chapter.
- Visit automationdirect.com and identify component options and prices necessary to build a simple PLC system for your own use.
 - CLICK Basic PLC processor model C0-00DD1-D recommended, model C0-10DD1E-D is more expensive but offers Ethernet connectivity
 - CLICK AC power supply model C0-00AC recommended
 - CLICK discrete “combo” I/O module, model C0-16CDD1
 - Programming cable assembly model EA-MG-PGM-CBL recommended, not necessary for Ethernet-ready PLC
 - *IMPORTANT NOTE: we have CLICK PLC processors already installed at multiple locations in our lab ready-to-use with I/O modules you purchase for yourself. If you do not plan to build your own complete PLC system, the pre-installed and networked PLC processor system in our lab will save you significant expense!*

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_0026

Theory session 51

Source text – *Semiconductor Logic Gates* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Bicycle headlamp alarm
 - Logic gate limitations
 - TTL versus CMOS logic
 - Logic gate currents
 - Open collector/drain logic gates
 - Tri-state output logic gates
 - Logic levels
 - Voltage level translation
- Complete “Discrete analysis of a bipolar OR gate” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Discrete analysis of a CMOS NAND gate” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Voltages in a TTL gate” in the Quantitative Reasoning section of the Questions chapter.
- Run at least one simulation of a combination logic-controlled motor (Circuit_009) 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.

Additional resources:

- `tshoot` circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_009.
file wt_0027

Theory session 52

Source text – *Digital Diagnostic Tools* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Multimeters
 - Logic probes and pulser
 - Oscilloscopes
 - Assembled board testing
- Complete “Pull-down resistor sizing” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Logic probe and pulser” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “Identifying possible 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.

Additional resources:

- tshoot circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_009.
file wt_0169

Theory session 53

Source text – *Digital Numeration* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Unsigned integers
 - Signed integers
 - Shorthand representations of digital words
- Read, outline, and reflect on the A binary resistance box section of the Historical References chapter.
 - Determine the amount of electrical resistance represented by the brass plug configurations shown in figures 29 and 30 of Maxwell’s text
 - Identify how you would place these plugs to obtain various resistance values within the range of each of these devices
 - Represent these plug positions as binary numbers, and also as hexadecimal numbers
- Complete “Counting in binary, octal, and hexadecimal” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Using Python to convert between bases” 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_0029

Theory session 54

Source text – *Digital Numeration* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Decimal conversions
 - Incompatible format errors
- Complete “Decimal to binary conversions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Signed integer conversion table” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Microcontroller driving an LED array” 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_0030

Theory session 55

Source text – *Introduction to PLCs* learning module

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

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

- Read, outline, and reflect on the Simplified Tutorial chapter in its entirety.
- Examine and reflect on the Example: NAND function in a PLC section of the Case Tutorial chapter, and answer the following questions:
 - Explain the relationship between each virtual contact's and virtual coil's *color highlighting* shown on the Relay Ladder Logic (RLL) program display and the real-world electrical statuses of switches and lamp shown in the PLC schematic diagram.
- Complete "Relay ladder logic analogy for a PLC" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining process switch stimuli from color highlighting" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Integer format error between PLC and HMI" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

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:

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

file wt_0264

Theory session 56

Source text – *Digital Codes* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Read, outline, and reflect on the Ancient serial data communication section of the Historical References chapter.
- Complete “ASCII-coded message” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Binary and Gray rotary encoders” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Failed ASCII bit” in the Diagnostic Reasoning section of the Questions chapter.
- Complete “Failed encoder photodetector” 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_0031

Theory session 57

Source text – *Combinational Logic* learning module

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

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

- Read, outline, and reflect on the following sections of the Tutorial chapter:
 - Universality
 - Combinational relay logic
 - Boolean expressions into circuits
- Read, _____ outline, _____ and _____ reflect _____ on the NASA’s Apollo Guidance Computer section of the Historical References chapter and answer the following questions:
 - Explain how the BJT-based logic gate functioned by applying “thought experiments” whereby you assume certain input states and determine the circuit’s output state for each input combination
 - Explain why NASA chose to design an entire computer using nothing but NOR gates
- Complete “Boolean expressions from gate circuits” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Gate circuits from Boolean expressions” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Relay circuits from Boolean expressions” 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:

- tshoot circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_009.
file wt_0107

Theory session 58

Source text – *Combinational Logic* learning module

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

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

- Read, outline, and reflect on the following section of the Tutorial chapter:
→ Truth tables into circuits
- Complete “Triple-redundant power supply” in the Conceptual Reasoning section of the Questions chapter.
- Complete “Gate circuit from a truth table” in the Quantitative Reasoning section of the Questions chapter.
- Complete “Relay circuit from a truth table” 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.
- tshoot circuit troubleshooting simulation software in the “no-fault” mode (`./tshoot -nofault`), particularly circuit_009.
file wt_0106

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 digital circuit 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:

Check-list of Foundational Concepts

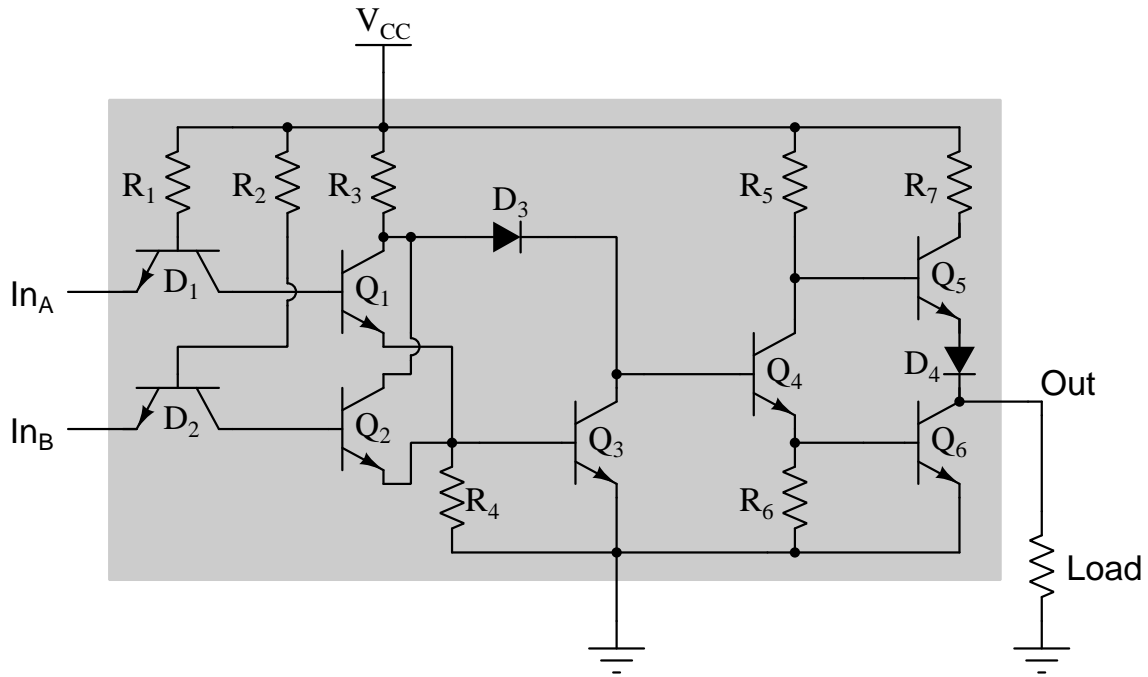
- | | |
|---|--|
| <input type="checkbox"/> Conservation of Energy | <input type="checkbox"/> Conduction in semiconductors |
| <input type="checkbox"/> Conservation of Electric Charge | <input type="checkbox"/> Behavior of PN junctions |
| <input type="checkbox"/> Behavior of sources versus loads | <input type="checkbox"/> Behavior of BJTs |
| <input type="checkbox"/> Ohm's Law | <input type="checkbox"/> Behavior of FETs |
| <input type="checkbox"/> Joule's Law | <input type="checkbox"/> Sourcing versus sinking current |
| <input type="checkbox"/> Effects of opens versus shorts | <input type="checkbox"/> Behavior of thyristors |
| <input type="checkbox"/> Properties of series networks | <input type="checkbox"/> Switch/gate/Boolean equivalence |
| <input type="checkbox"/> Properties of parallel networks | <input type="checkbox"/> Truth tables for basic gate types |
| <input type="checkbox"/> Kirchhoff's Voltage Law | <input type="checkbox"/> Voltages relating to logic states |
| <input type="checkbox"/> Kirchhoff's Current Law | <input type="checkbox"/> DeMorgan's Theorem |
| <input type="checkbox"/> Maximum Power Transfer Theorem | |
| <input type="checkbox"/> Superposition Theorem | |
| <input type="checkbox"/> Thevenin's and Norton's Theorems | |
| <input type="checkbox"/> Electric fields and capacitance | |
| <input type="checkbox"/> Magnetic fields and inductance | |
| <input type="checkbox"/> Inverse-exponential growth/decay | |

Check-list of problem-solving strategies

- ☐ Thought experiments
- ☐ Limiting cases
- ☐ Annotation of diagram(s)
- ☐ Add quantities to a qualitative problem
- ☐ Analyze a quantitative problem qualitatively
- ☐ Sketch graphs to illustrate numerical concepts
- ☐ Assume a final result and work backwards

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.

System #1

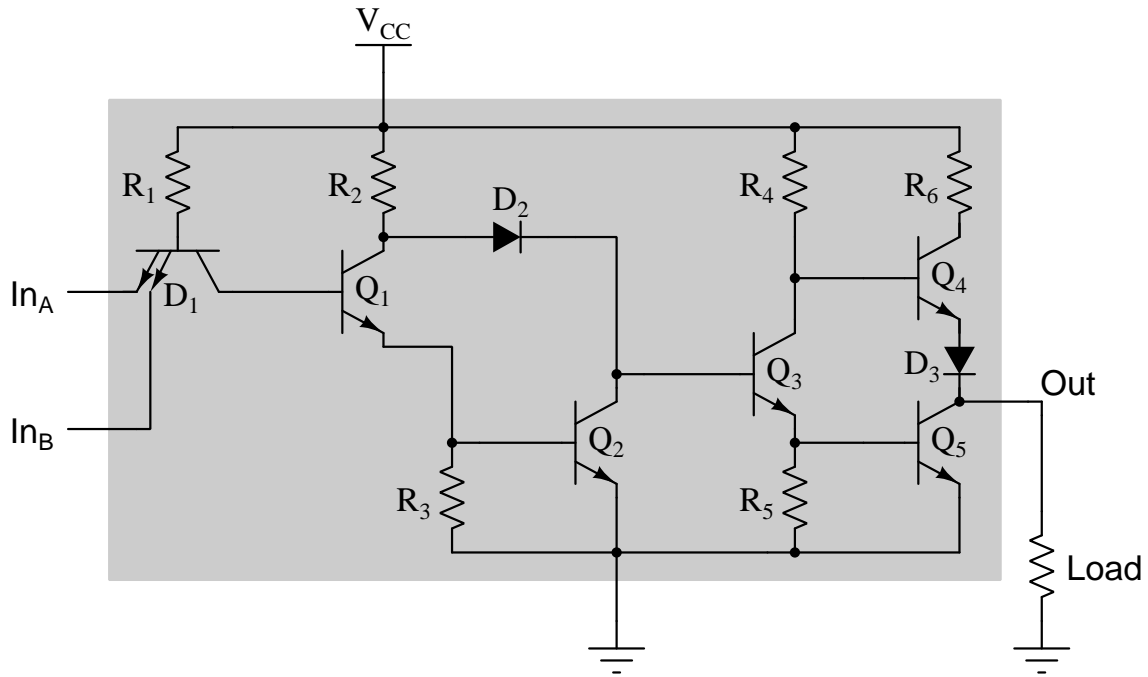


Grading

- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is high
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is high

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

System #2

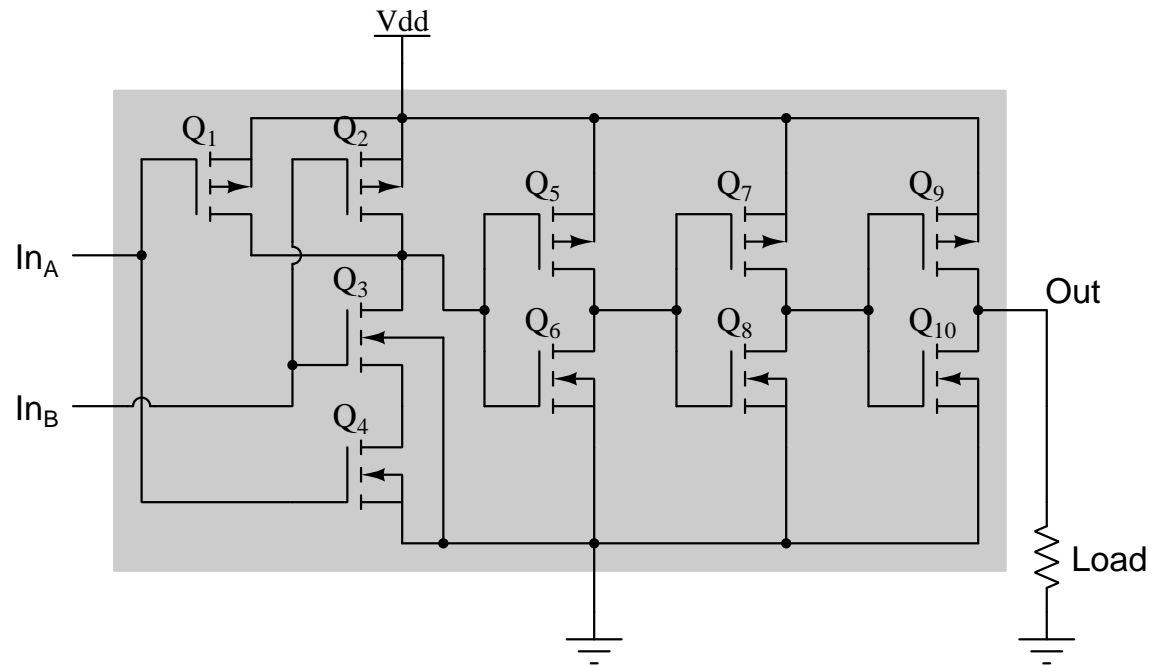


Grading

- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is high
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is high

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

System #3

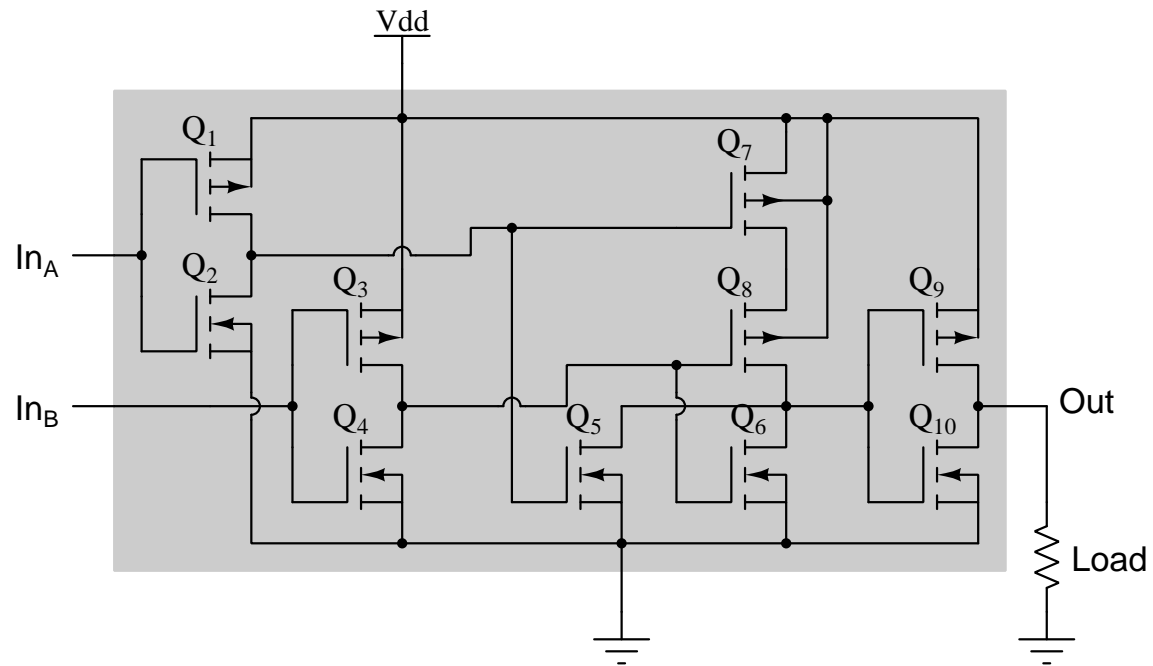


Grading

- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is high
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is high

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

System #4



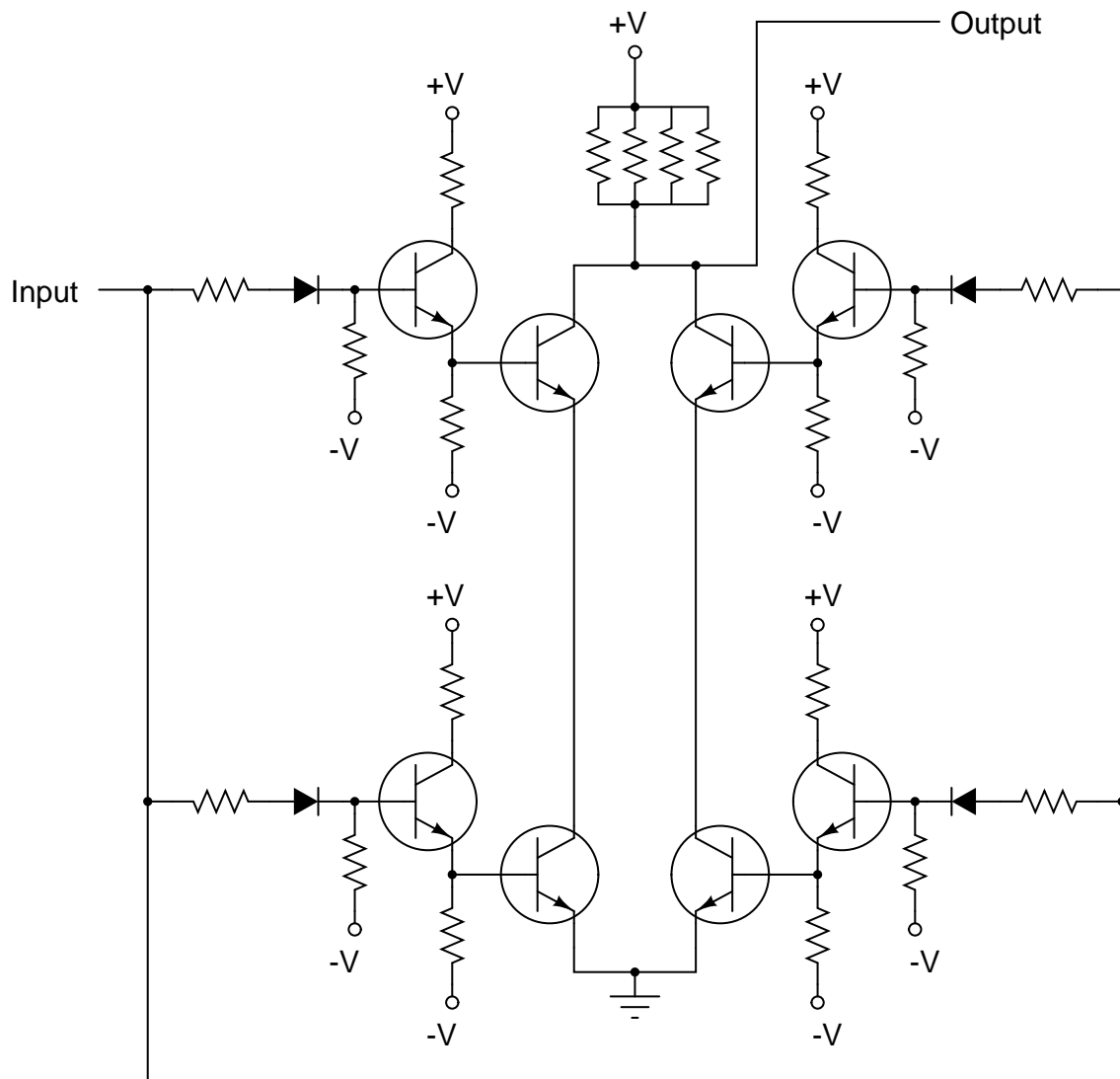
Grading

- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is low and input B is high
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is low
- ☐ [25%] Status (on/off) of every transistor when input A is high and input B is high

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

System #5

Note: this is a redundant inverter (NOT) gate developed by NASA for some of the digital logic inside of satellite, capable of operating correctly in the event that any transistor happened to fail open or fail shorted (collector-emitter).



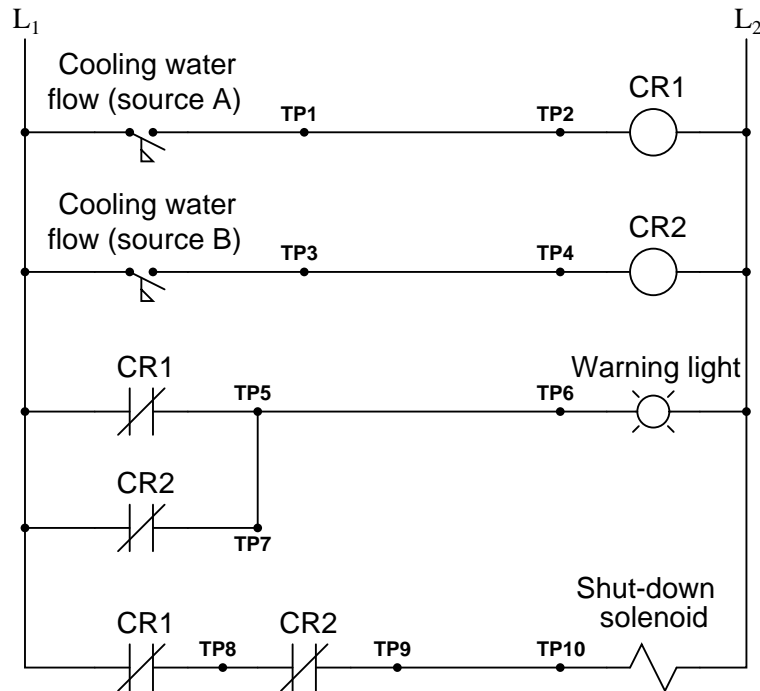
Grading

- ☐ [25%] Status (on/off) of every transistor when input is low, assuming all components healthy
- ☐ [25%] Status (on/off) of every transistor when input is high, assuming all components healthy
- ☐ [25%] Status (on/off) of every transistor when input is high, assuming one transistor failed open (your choice)
- ☐ [25%] Status (on/off) of every transistor when input is high, assuming one transistor failed shorted (your choice)

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

System #6

Note: a water-cooled generator at a power plant has two sources of cooling water flow, each source equipped with a flow switch that returns to its normally-open status if the water flow through the pipe stops.



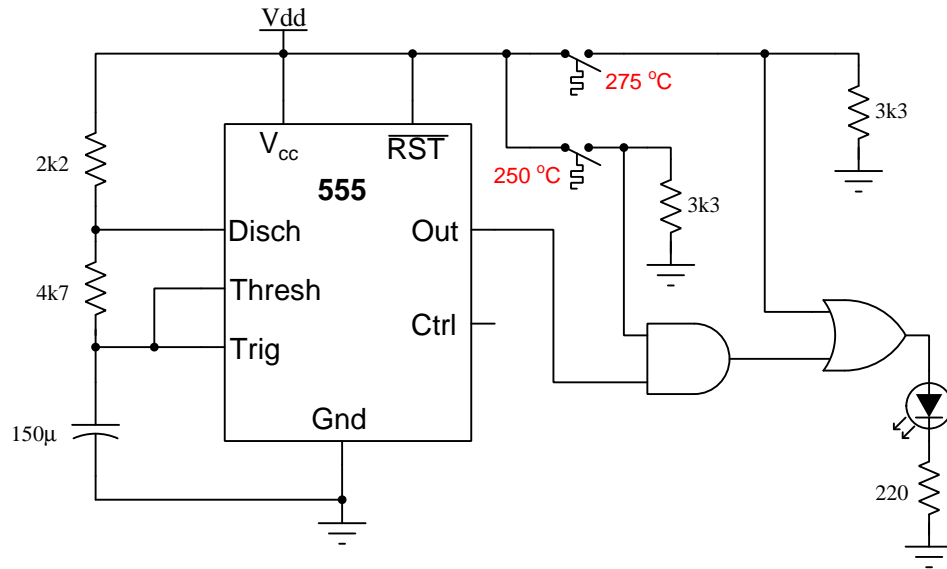
Grading

- ☐ [20%] Presence or absence of current in each rung when cooling water A is stopped and cooling water B is stopped
- ☐ [20%] Presence or absence of current in each rung when cooling water A is stopped and cooling water B is flowing
- ☐ [20%] Presence or absence of current in each rung when cooling water A is flowing and cooling water B is stopped
- ☐ [20%] Presence or absence of current in each rung when cooling water A is flowing and cooling water B is flowing
- ☐ [20%] Identify whether the shut-down solenoid must energize or de-energize to shut down the generator

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

System #7

Note: the two temperature switches sense the temperature of air inside of a laboratory oven, with each of their settings representing an excessively-hot condition (one more severe than the other).



Grading

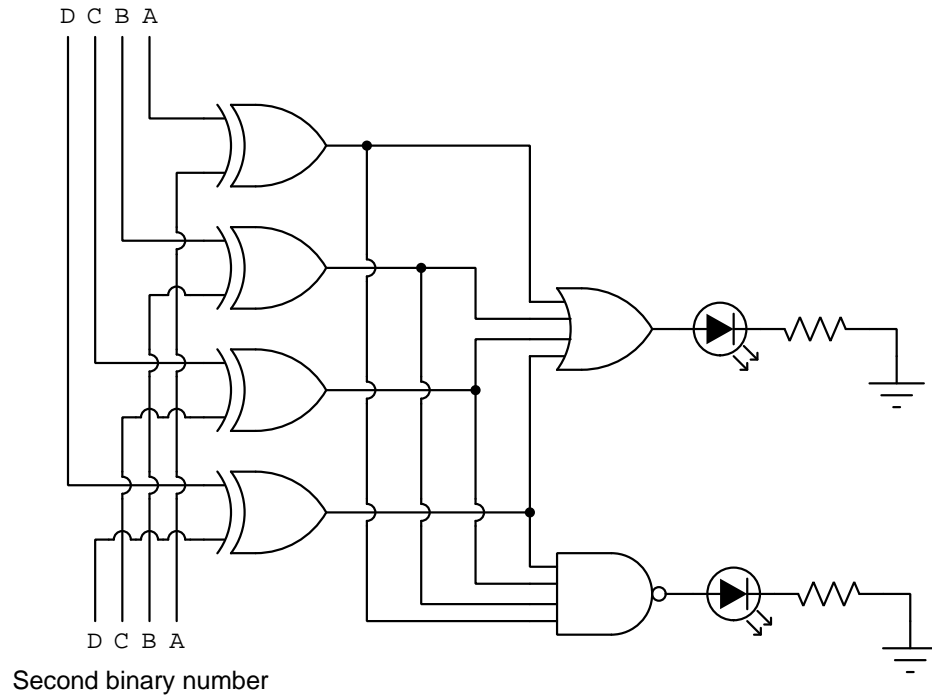
- ☐ [20%] Logic gate states and LED status when temperature is 220 °C
- ☐ [20%] Logic gate states and LED status when temperature is 260 °C
- ☐ [20%] Logic gate states and LED status when temperature is 290 °C
- ☐ [20%] Identify how to (*speed up* / *slow down*) the LED's blinking rate
- ☐ [20%] Effect on system functionality if ____ fails open

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

System #8

Note: the D-C-B-A input lines connect to two binary-number digital sources.

First binary number



Grading

- ☐ [20%] Identify condition(s) necessary to energize only the upper LED
- ☐ [20%] Identify condition(s) necessary to energize only lower LED
- ☐ [20%] Identify condition(s) necessary to energize both LEDs
- ☐ [20%] Effect on system functionality if upper-most XOR gate fails with a (*high* / *low*) output
- ☐ [20%] Modify schematic to energize an LED *only* if the two binary numbers match

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

Theory session 60

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

- (Question #1) Determine logic states within a combinational logic circuit.
Logic function truth tables, logic levels in TTL and CMOS circuits, effects of opens vs. shorts
- (Question #2) Design and sketch a combinational logic gate circuit to fulfill a three-input truth table.
Logic function truth tables, Boolean representation of logic functions, SOP/POS Boolean expressions
- (Question #3) Select appropriate component values (e.g. resistor resistance) for a digital logic gate circuit driving a heavy load.
Ohm's Law, Joule's Law, Kirchhoff's Laws, properties of series and parallel networks, BJT behavior, FET behavior, logic levels in TTL and CMOS circuits, logic function truth tables
- (Question #4) Convert between different forms of digital numeration (e.g. binary, octal, hexadecimal, decimal).
Signed binary integers, unsigned binary integers, octal notation, hexadecimal notation
- (Question #5) Determine possible faults in a combinational logic gate or relay ladder logic circuit.
Logic function truth tables, properties of series and parallel networks, effects of opens vs. shorts, relay behavior