

## Electricity and Electronics II

Last update 2 March 2024

Session	Topic	Theory	Lab	Comments
Session 01	Introduction			
Session 02	Series and parallel review			
Session 03	Series-parallel networks (I)			
Session 04	Series-parallel networks (II)			
Session 05	Capacitance/inductance review			
Session 06	Right-triangle trigonometry			
Session 07	Introduction to AC			
Session 08	Oscilloscope review			
Session 09	Electrical hazards review			
Session 10	Power supply circuits review			
Session 11	Troubleshooting practice			
Session 12	WHITEBOARD INTERVIEWS			

Session	Topic	Theory	Lab	Comments
Session 13	R, X, and Z			
Session 14	Series AC circuits (I)			
Session 15	Series AC circuits (II)			
Session 16	Parallel AC circuits (I)			
Session 17	Parallel AC circuits (II)			
Session 18	Resonance			
Session 19	Frequency-domain analysis (I)			
Session 20	Frequency-domain analysis (II)			
Session 21	Elementary filter circuits (I)			
Session 22	Elementary filter circuits (II)			
Session 23	Troubleshooting practice			
Session 24	WHITEBOARD INTERVIEWS			

Session	Topic	Theory	Lab	Comments
Session 25	Transistors review			
Session 26	Logic gates review			
Session 27	Comparators review			
Session 28	Digital numeration review			
Session 29	Combinational logic (I)			
Session 30	Combinational logic (II)			
Session 31	Multiplexers and demultiplexers			
Session 32	Latching logic			
Session 33	Shift registers			
Session 34	Counters			
Session 35	Troubleshooting practice			
Session 36	WHITEBOARD INTERVIEWS			

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Session	Topic	Theory	Lab	Comments
Session 37	Microcontrollers and PLCs (I)			
Session 38	Microcontrollers and PLCs (II)			
Session 39	Microcontrollers and PLCs (III)			
Session 40	Digital codes			
Session 41	Serial data communication (I)			
Session 42	Serial data communication (II)			
Session 43	RS-232/422/485 serial			
Session 44	Ethernet			
Session 45	IP/TCP/UDP			
Session 46	Serial device control			
Session 47	Troubleshooting practice			
Session 48	WHITEBOARD INTERVIEWS			

#### Essential information about this course:

- This course is a mix of theory and hands-on experiments. Each class session runs two hours long, the first hour focused on theory and the second hour on application.
- *There will be no lecture during the theory portion of each class session.* At-home reading assignments replace lecture, allowing us to spend our class time together discussing the text and solving problems. The basic expectation for each student is a good-faith effort every day to comprehend the material, and full engagement with classmates during class sessions as we challenge and support one another's learning.
- *The experiments you will run are not pre-designed.* You will plan and execute each experiment, just like a real scientific experiment where the outcome is not necessarily known.
- You are not expected to master all concepts on your own. If and when you are confused, try to identify as precisely as you can the source of your confusion. This is extremely helpful to the instructor. Document all questions that come to mind, and raise those questions during class.
- Expect to make mistakes, and to have those mistakes gently and respectfully corrected. Be gracious with yourself and with others in this class as they make their own mistakes. *This is a learning community, and together we will de-stigmatize error.*
- You should budget a minimum of 20 hours per week for this course, approximately 10 hours in-class with discussions and experimentation, and approximately 10 hours out-of-class preparation in the form of reading and writing.
- This course document and all reading assignments are open-source and publicly available at the *Modular Electronics Learning Project* webpage (<https://ibiblio.org/kuphaldt/socratic/model>)

## Required tools, supplies, components, and software

### Tool List

- 18-24 gauge wire cutter/stripper pliers  
→ *e.g. 8-inch 4-way wire stripper from Harbor Freight, about \$5*
- Small needle-nose pliers  
→ *e.g. Pittsburgh 5-3/4-inch pliers from Harbor Freight, about \$2*
- Small diagonal (side) wire cutters  
→ *e.g. Pittsburgh 6-inch pliers from Harbor Freight, about \$3*
- Screwdrivers, slotted and phillips
- Inexpensive multimeter  
→ *e.g. 7-function digital multimeter from Harbor Freight, about \$7*  
→ *e.g. Gardner-Bender digital or analog multimeters from The Home Depot, about \$18*
- Digital oscilloscope  
→ *e.g. PicoScope model 2204A, about \$170*  
→ *e.g. Siglent SDS1052DL+, about \$300*
- Signal generator  
→ *Square-wave and triangle-wave at minimum*
- Set of jumper wires with alligator-clip ends  
→ *e.g. KAIWEETS 10-piece set from Amazon.com, about \$5*
- Solderless breadboard
- Terminal blocks (at least ten terminals mounted on DIN rail)

### Software List (all free downloads)

- Download – **Python** (will use Python interpreter shell as a powerful scientific calculator)  
→ Alternatively, use [www.python.org/shell](http://www.python.org/shell) online interpreter
- Download – **Picoscope** interface software for the model 2204A oscilloscope
- Download – **Arduino** development software
- Download – **WSL** (Windows Subsystem for Linux) and **tsshoot** circuit troubleshooting simulator software  
→ Purportedly, **termux** offers a similar command-line environment for Android smart phones
- Download – **WireShark** network monitoring software
- Download – **SEL AcSELeator** protective relay management software
- Download – **termite** or **SEL BlueTerm** serial terminal software
- Download – **CLICK Programming** software for Automation Direct PLCs

## Supply List

- Rolls of 22-gauge solid wire for use with breadboards and soldering and magnetism
  - e.g. *TUOFENG 22 awg hook up wire kit from Amazon.com*, about \$15
- Small solar panel (25 Watts or less)
- 120 VAC power cord
- Passive components
  - Assortment of 1/4 Watt resistors (1 k Ohm through 100 k Ohm)
  - Low-value “shunt” resistors (between 1 Ohm and 10 Ohms)
  - Pushbutton switches
  - Ceramic capacitors (0.1 uF, 1 uF)
  - Aluminum electrolytic capacitors (10 uF, 100 uF, 1000 uF)
  - DC “hobby” permanent magnet motor
  - AC shaded-pole induction motor (e.g. bathroom ventilation fan motor)
  - CdS photocells
  - Moving-coil speaker
  - Control power transformer (step-down from 120 VAC to 12 VAC)
  - “Ice-cube” style electromechanical relays
  - 1N4001 rectifying diodes
  - Bridge rectifier assemblies
  - Low-voltage incandescent lamps
  - Light-emitting diodes
  - AGC fuses and fuseholders suitable for 120 VAC
- Active components
  - LM7805 voltage regulators
  - LM339 or CA339 quad comparator ICs
  - 555 timer ICs
  - Power BJTs (e.g. TIP31, TIP32)
  - Power MOSFETs (e.g. IRF510)
  - CD4071 or 74HC32 quad 2-input OR gate ICs
  - CD4001 or 74HC02 quad 2-input NOR gate ICs
  - CD4081 or 74HC08 quad 2-input AND gate ICs
  - CD4011 or 74HC00 quad 2-input NAND gates
  - CD4070 quad 2-input XOR gate ICs
  - CD4013 or 74HC74 dual D flip-flop ICs
  - CD40174 hex or 74HC273 octal D flip-flop ICs
  - CD4027 or 74HC73 dual JK flip-flop ICs
  - CD4029 presettable up/down counter ICs
  - CD4069 or 74HC04 hex inverter gate ICs
  - CD4511 BCD/7-segment LED latch decoder/driver ICs
  - CD40106 hex inverter Schmitt trigger ICs
  - 74HC151 single 8-input multiplexer ICs
  - 74HC138 single 8-input demultiplexer ICs
  - MAX232CPE (or similar) RS-232 transceiver ICs
  - Arduino microcontroller (the “Nano” model works well with solderless breadboards)
  - Automation Direct “CLICK” PLC processor with 24 VDC I/O
  - Automation Direct “CLICK” PLC power supply

## Session 01

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

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

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

- Read the Case Tutorial and Simplified Tutorial chapters in their entirety.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How may we define voltage in scientifically accurate terms?
  - How may we define current in scientifically accurate terms?
  - Explain how voltage is always a quantity relative between two points rather than being an absolute quantity measurable at a single point
  - What is the significance of the test lead colors (red, black) on a voltmeter or ammeter?
  - What is an “open” fault guaranteed to prohibit in an electric circuit?
  - What is a “shorted” fault guaranteed to prohibit in an electric circuit?

Discuss format for this and all future class sessions:

- *Complete the pre-class assignment to the best of your ability*
- *Dialogue with the instructor during class to make sense of the topic*
- *Work together on hands-on circuit-building and diagnostic activities to apply the theory concepts*
- *Roles and expectations* – we are here to learn, to grow, and to both challenge and support one another!

You will also work with your instructor to install free software if you plan to use your own personal computer (reference the Software List shown earlier in this document).

Finally, you will work with your instructor to become familiar with tools and supplies listed in the *Required tools, supplies, components, and software* list (see previous page).

*(time permitting)* – elementary circuit troubleshooting using **tshoot** (circuit #000)

## Session 02

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

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

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

- Read the Simplified Tutorial chapter in its entirety and summarize the properties of series networks. Also define *voltage*, *current*, *resistance*, and *power*.
- Show how to calculate the voltages and currents shown in the “Example: Three-resistor circuit” section of the Case Tutorial chapter.

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

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

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

- Read the Simplified Tutorial chapter in its entirety and summarize the properties of parallel networks. Also contrast electrical *sources* versus *loads*.
- Comment on the use of V/I/R tables shown in these tutorial chapters to organize all parameters in a series or a parallel circuit.

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- ☐ Recommendation: use resistors no smaller than 1 k $\Omega$  and no larger than 100 k $\Omega$  for the best results
- Concept: voltage and current in series-connected networks
  - Build a circuit consisting of multiple resistors connected in series with a voltage source and prove with a multimeter the relationship between individual voltage drops and total (source) voltage for a series network, as well as the relationship between individual resistor currents and total (source) current for a series network
  - Use a V/I/R table to manage all calculations
- Concept: voltage and current in parallel-connected networks
  - Build a circuit consisting of multiple resistors connected in parallel with a voltage source and prove with a multimeter the relationship between individual voltage drops and total (source) voltage for a parallel network, as well as the relationship between individual resistor currents and total (source) current for a parallel network
  - Use a V/I/R table to manage all calculations
  - Predict and test where you expect to measure zero voltage in this powered circuit

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## Session 03

**Source text** – *Series-Parallel Circuits* learning module

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

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

- Read the Full Tutorial chapter in its entirety.
- Answer the following questions to the best of your ability, referencing the tutorial as applicable:
  - How may we define voltage in terms of fundamental conservation law(s)?
  - How may we define current in terms of fundamental conservation law(s)?
  - What distinguishes energy from power?
  - What does it mean for points to be “electrically common” with each other?
  - Why must current be the same for all components connected in series?
  - Why must voltage be the same for all components connected in parallel?
  - What is Kirchhoff’s Voltage Law (KVL), and what fundamental conservation law is it based on?
  - What is Kirchhoff’s Current Law (KCL), and what fundamental conservation law is it based on?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors no smaller than 1 k $\Omega$  and no larger than 100 k $\Omega$  for the best results
- Concept: total resistance of a series-parallel resistor network
  - Connect at least three resistors together to form a series-parallel resistor network, then predict that network’s total resistance and verify using an ohmmeter
- Concept: series-parallel circuit analysis
  - Sketch series-parallel circuits on paper using battery and resistor values you know are in your parts collection, reduce those circuits step-by-step to a single source and single equivalent resistance each, and “expand” those simplified circuits back to their original forms while calculating all component voltages and currents
  - Build those same series-parallel circuits, measuring voltages and currents to confirm predicted values
- Concept: (review) voltage divider circuit troubleshooting
  - Use the `tshoot` circuit simulation program to diagnose faults in a voltage divider circuit (Circuit #001) consisting of a voltage source, fuse, toggle switch, and three series-connected resistors

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## Session 04

**Source text** – *Series-Parallel Circuits* learning module

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

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

- Practice analyzing series-parallel circuits
  - “Three-resistor circuits” found in the Quantitative Reasoning section of the Questions chapter
  - “Mixed-source circuits” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors no smaller than 1 k $\Omega$  and no larger than 100 k $\Omega$  for the best results
- Concept: series-parallel circuit analysis
  - Sketch series-parallel circuits on paper using battery and resistor values you know are in your parts collection, reduce those circuits step-by-step to a single source and single equivalent resistance each, and “expand” those simplified circuits back to their original forms while calculating all component voltages and currents
  - Build those same series-parallel circuits, measuring voltages and currents to confirm predicted values
- Concept: (review) current divider circuit troubleshooting
  - Use the `tshoot` circuit simulation program to diagnose faults in a current divider circuit (Circuit #002) consisting of a current source, toggle switch, and three parallel-connected resistors



## Session 05

**Source text** – *Capacitance and Inductance* learning module

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

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

- Read the following sections of the Full Tutorial chapter:
  - Energy storage in fields
  - Capacitance and inductance compared
  - Applications of capacitance and inductance
- Answer the following questions to the best of your ability:
  - What is necessary in order to create capacitance in a system?
  - What is necessary in order to create inductance in a system?
  - Calculate the amount of energy stored in a  $47\ \mu\text{F}$  capacitor when connected to a 30 VDC source
  - Calculate the total amount of energy stored in a network of two parallel-connected  $47\ \mu\text{F}$  capacitors when connected to a 30 VDC voltage source
  - Calculate the total amount of energy stored in a network of two series-connected  $47\ \mu\text{F}$  capacitors when connected to a 30 VDC voltage source
  - Calculate the amount of energy stored in a 100 mH inductor when connected to a 50 mA current source
  - Calculate the total amount of energy stored in a network of two parallel-connected 100 mH inductors when connected to a 50 mA current source
  - Calculate the total amount of energy stored in a network of two series-connected 100 mH inductors when connected to a 50 mA current source
  - Based on these calculated energy values, determine which type of connection (series or parallel) between two capacitors results in more capacitance, and which type of connection between two inductors results in more inductance

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: storing energy in a capacitor
  - Conduct an experiment as outlined in the Case Tutorial chapter demonstrating how energy may be stored within a capacitor
  - Re-try the experiment with multiple capacitors connected in series
  - Re-try the experiment with multiple capacitors connected in parallel
- Concept: storing energy in an inductor
  - Conduct an experiment as outlined in the Case Tutorial chapter demonstrating how energy may be stored within an inductor
  - Re-try the experiment with multiple inductors connected in series
  - Re-try the experiment with multiple inductors connected in parallel

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Source text – *Trigonometry* learning module

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

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

- Read, outline, and reflect on the Tutorial chapter in its entirety.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What is a *radian*?
  - How do we apply the *Pythagorean Theorem*?
  - How is the *sine* function defined in terms of a right triangle?
  - How is the *cosine* function defined in terms of a right triangle?
  - How is the *tangent* function defined in terms of a right triangle?
  - At what angle values do these trigonometry functions reach simple values (e.g. 1, -1,  $\frac{1}{2}$ , etc.)?
- Answer all points of the following questions found in the learning module:
  - “Squaring a house foundation” found in the Conceptual Reasoning section of the Questions chapter
  - “Unknown side lengths” found in the Quantitative Reasoning section of the Questions chapter
  - “Unknown angles and side lengths” found in the Quantitative Reasoning section of the Questions chapter
  - “Find the mistake(s)” found in the Diagnostic Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors no smaller than 1 k $\Omega$  and no larger than 100 k $\Omega$  for the best results
- Concept: (review) loaded voltage divider circuit troubleshooting
  - Use the **tshoot** circuit simulation program to diagnose faults in a loaded voltage divider circuit (Circuit #004) consisting of a voltage source, two toggle switches, and five resistors

## Session 07

**Source text** – *AC Quantities and Measurements* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Answer all points of the following question found in the learning module:
  - “AC voltage oscillographs” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: AC measurements using a multimeter
  - Use a small AC induction motor to generate tiny AC voltages, and determine the relationship between shaft speed and frequency, between shaft speed and AC voltage
  - Build a voltage divider circuit using a resistor and photocell, then measure the frequency of pulsing DC voltage when you pass your fingers in front of the photocell to alternately block and pass ambient light
  - Use a signal generator to output low-voltage AC, determining the relationship between knob position and measured frequency
  - Measure AC line frequency available at a wall power receptacle
- Concept: 555 timer (astable) oscillator
  - Follow the instructions on a 555 timer IC datasheet to build an astable oscillator
  - Select components to achieve a frequency of approximately 1 kHz
- Concept: (review) loaded voltage divider circuit troubleshooting
  - Use the `tshoot` circuit simulation program to diagnose faults in a loaded voltage divider circuit (Circuit #004) consisting of a voltage source, two toggle switches, and five resistors

Source text – *Oscilloscopes* learning module

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

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

- Read the Simplified Tutorial chapter in its entirety.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What is represented on the vertical axis of an oscilloscope display?
  - What is represented on the horizontal axis of an oscilloscope display?
  - How can you calculate the frequency of an AC signal on an oscilloscope display?
  - What are some things an oscilloscope can measure that a multimeter cannot?
  - How may we quantify the magnitude of any voltage signal based on its displayed trace?
  - How may we quantify the period of any voltage signal based on its displayed trace?
  - What is the relationship between period and frequency for any given waveform?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: testing AC voltage sources
  - Use an oscilloscope to measure the voltage output by the stator winding of a small AC motor as you spin its shaft (using it as a generator)
  - Use an oscilloscope to measure the voltage output by a small loudspeaker as you touch its cone
  - Use an oscilloscope to measure the voltage output by an astable 555 timer circuit
- Concept: measuring AC amplitude
  - Use the “single-trace” function of an oscilloscope to capture and freeze a transient AC voltage on the screen, then measure its peak and peak-to-peak amplitude values
  - Compare the voltage measurement accuracy of an oscilloscope versus a AC voltmeter sensing the same signal output by a signal generator circuit, over a range of frequencies
- Concept: measuring AC frequency
  - Use the “single-trace” function of an oscilloscope to capture and freeze a transient AC voltage on the screen, then measure its period and frequency
  - Compare the frequency measurement accuracy of an oscilloscope versus a AC voltmeter sensing the same signal output by a signal generator circuit

**Source text** – *Electrical Hazards* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Electric shock and burn hazards
  - Hot, neutral, and ground power conductors
  - The National Electrical Code (NFPA 70)
- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Differentiate between voltage, current, resistance, energy, and power
  - Electrically common points
  - Disconnect switch
  - Bonding cable
  - Hot, Neutral, and Ground conductors
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Explain how Ohm's Law and Joule's Law are relevant to electrical safety.
  - How much electricity is hazardous to the human body (note that this is a complex question and has multiple answers!)?
  - How do we keep ourselves safe when working with electric circuits capable of delivering lethal voltages and currents to our bodies?
  - What does the NEC specify?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: 120 Volt power receptacle wiring
  - Use an AC voltmeter to identify the Hot, Neutral, and Ground terminals on a standard 120 Volt electrical power receptacle
- Concept: stored energy
  - Determine if and how a capacitor could store a dangerous amount of energy, then demonstrate the concept (if possible) at harmless energy levels
  - Determine if and how an inductor could store a dangerous amount of energy, then demonstrate the concept (if possible) at harmless energy levels
- Concept: lock-out, tag-out procedure
  - Build a simple electric lamp or motor circuit with a switch as well as a fuse, and then demonstrate proper lock-out, tag-out technique
  - If there is no provision for a lock, know that the NFPA 70E safety standard permits tagging (only) of *two* disconnects as a substitute

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## Session 10

**Source text** – *Brute-Force Power Supplies* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts apply to power supply circuits.

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

The balance of your class session time should be used to perform hands-on experiments exploring those same principles and strategies. Identify principles and/or circuit examples from the text that you would like to explore in more detail, formulate testable hypotheses, and then conduct experiments testing those hypotheses. *Note: some learning modules contain Case Tutorial chapters, which are another place to check for experimental ideas!*

Also, draft a list of teaching topics for the next (Teach-Back) session. Please (1) keep the topics as simple as possible, and only build in complexity *if* the learners prove their readiness; (2) DO NOT RUSH the learning process; (3) place learners in a role that is as *active* as possible so you will be able to tell how well they are learning. This same list will prove useful in identifying Whiteboard Interview topics you will be answering in a subsequent session!

## Session 11

In today's session we will spend the entire time practicing the analysis and diagnosis of faults in circuits, also known as "troubleshooting". Not only is this a highly valuable skill to develop, but it also provides excellent opportunity to apply foundational concepts such as the effects of opens and shorts, Ohm's Law, Kirchhoff's Laws, etc. Several options exist for troubleshooting practice, which the instructor may select at will:

### Predicting consequences of faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, choose at random different faults that could be placed within this circuit (e.g. wires broken open, components failing open, components failing shorted) and predict how each of these faults will impact voltages and currents throughout the circuit. Your instructor will advise which faults are safe to introduce, versus which may lead to component damage or safety hazard(s). After making your predictions, introduce the (safe) fault and then use test equipment to verify whether or not your predictions were correct.

### Identifying hidden faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, identify specific points within the schematic diagram useful as "test points" between which you may take voltage measurements. If in doubt, simply include one test point for each and every electrically distinct point in the circuit. Then, connect long wires from numbered terminals on a terminal block to these test points, so each test point may be accessed for voltage measurement some distance from the breadboard. Your instructor will have you exit the room, place a fault in the breadboarded circuit, then cover up the breadboard with a box or cloth rag so the fault cannot be identified by visual inspection. Upon returning to the room, your task will be to identify the location and nature of the fault solely by taking voltage measurements between those numbered terminals, with the schematic diagram being your "road map" to the circuit.

### Using TSHOOT

A computer simulation program named TSHOOT exists for troubleshooting practice on simple circuits. It simulates all the steps described above for identifying hidden faults on a breadboarded circuit, but without the need for a physical circuit, a terminal block, or real test equipment. This program was developed for Unix-like operating systems, which means it runs natively on Linux or Apple PCs but requires WSL (Windows Subsystem for Linux) on Microsoft Windows PCs. 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`

Finally, we will brainstorm topics for the next session's "whiteboard interviews", where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.

## Session 12

Today's class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each "whiteboard interview" is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is "fair game" for these challenges, and together we will brainstorm possible topics during the previous session.

During your "interview" the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

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 real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.



## Session 13

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

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

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

- Read the Simplified Tutorial chapter in its entirety.  
→ *Work through all quantitative examples yourself, to prove you understand the math*
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How does reactance differ from resistance?
  - What is impedance, and how does it relate to reactance and resistance?
  - How does frequency affect the reactance offered by a capacitor?
  - How does frequency affect the reactance offered by an inductor?
  - What is a phasor diagram, and how is one useful for representing impedance values?
  - How do we mathematically sum impedance values for a series network?
- Use the Programming in Python section of the Programming References chapter as a reference for how to use the Python computer programming environment as a scientific calculator!
- Answer all points of the following questions found in the learning module:
  - “Resistances and reactances expressed as impedances” found in the Quantitative Reasoning section of the Questions chapter
  - “Simple AC circuits” found in the Quantitative Reasoning section of the Questions chapter
- Identify where in the text some of the following foundational concepts apply:
  - Ohm’s Law
  - Behaviors of sources versus loads

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 100 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: reactance of a capacitor powered by a 60 Hz source
  - Calculate the capacitive reactance ( $X_C$ ) of a capacitor given an AC frequency of 60 Hz, then check by powering the capacitor using secondary voltage of a step-down transformer energized by 120 VAC line power, using Ohm’s Law to derive reactance from measured AC voltage and AC current
- Concept: transformer primary winding reactance and inductance
  - Estimate the reactance of the step-down transformer’s primary winding by measuring its primary voltage and current when the secondary is open (i.e. not connected to any load)
  - Estimate the same winding’s inductance from that reactance value
  - Estimate the secondary winding’s inductance, given that inductance is proportional to the square of the number of turns of wire

file wte\_0059

## Session 14

**Source text** – *AC Series Circuits* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_ac\\_s.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_ac_s.pdf)

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Read the following sections of the Case Tutorial chapter and identify the foundational concept(s) applied in each of the calculations shown (i.e. the conceptual rationale for each calculation):
  - Example: series RL circuit
  - Example: series RC circuit
  - Example: series RLC circuit

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 100 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: RC networks powered by 60 Hz source
  - Build a simple series resistor-capacitor network and power it with low-voltage AC from the secondary winding of a step-down transformer energized by 120 VAC line power, then predict and measure all voltages and currents
  - Use an oscilloscope as well as a DMM (digital multimeter), comparing these two instruments’ advantages and disadvantages
  - Use series or parallel networks of identical resistors instead of a single resistor in this same circuit, then re-calculate and re-measure AC voltages and currents
  - Use series or parallel networks of identical capacitors instead of a single capacitor in this same circuit, then re-calculate and re-measure AC voltages and currents
  - Draw phasor diagrams to accompany all calculations, showing each quantity represented as a vector (note that vectors stack tip-to-tail only for electrical quantities known to *add* in this type of network)

## Session 15

**Source text** – *AC Series Circuits* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_ac\\_s.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_ac_s.pdf)

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

- Read the following sections of the Case Tutorial chapter and identify the foundational concept(s) applied in each of the calculations shown (i.e. the conceptual rational for each calculation):
  - Example: measuring series voltage phase shift
- Answer all points of the following questions found in the learning module:
  - “Series RL impedances” found in the Quantitative Reasoning section of the Questions chapter
  - “Series RC impedances” found in the Quantitative Reasoning section of the Questions chapter
  - “Inductor with winding resistance” found in the Quantitative Reasoning section of the Questions chapter
  - “Unknown capacitance” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 100 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: RC networks powered by 60 Hz source
  - Build a simple series resistor-capacitor network and power it with low-voltage AC from the secondary winding of a step-down transformer energized by 120 VAC line power, then predict and measure all voltages and currents
  - Use an oscilloscope to measure phase shift between any two voltages in the circuit (e.g. phase shift between  $V_{source}$  and  $V_R$ , between  $V_{source}$  and  $V_C$ , between  $V_R$  and  $V_C$ )
  - Use series or parallel networks of identical resistors instead of a single resistor in this same circuit, then re-calculate and re-measure AC voltages and voltage phase shifts
  - Use series or parallel networks of identical capacitors instead of a single capacitor in this same circuit, then re-calculate and re-measure AC voltages and voltage phase shifts
  - Draw phasor diagrams to accompany all calculations, showing each quantity represented as a vector (note that vectors stack tip-to-tail only for electrical quantities known to *add* in this type of network)
- Concept: (review) voltage divider circuit troubleshooting
  - Use the **tshoot** circuit simulation program to diagnose faults in a voltage divider circuit (Circuit #001) consisting of a voltage source, fuse, toggle switch, and three series-connected resistors

file wte\_0061

## Session 16

**Source text** – *AC Parallel Circuits* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_ac\\_p.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_ac_p.pdf)

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Read the following sections of the Case Tutorial chapter and identify the foundational concept(s) applied in each of the calculations shown (i.e. the conceptual rationale for each calculation):
  - Example: parallel RC circuit
  - Example: parallel RL circuit
  - Example: parallel RLC circuit

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 10 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: RC networks powered by 60 Hz source
  - Build a simple parallel resistor-capacitor network and power it with low-voltage AC from the secondary winding of a step-down transformer energized by 120 VAC line power, then predict and measure all currents (using *shunt resistors* for inferential measurement of current)
  - Use an oscilloscope as well as a DMM (digital multimeter), comparing these two instruments’ advantages and disadvantages
  - Use series or parallel networks of identical resistors instead of a single resistor in this same circuit, then re-calculate and re-measure AC voltages and currents
  - Use series or parallel networks of identical capacitors instead of a single capacitor in this same circuit, then re-calculate and re-measure AC voltages and currents
  - Draw phasor diagrams to accompany all calculations, showing each quantity represented as a vector (note that vectors stack tip-to-tail only for electrical quantities known to *add* in this type of network)

Source text – AC Parallel Circuits learning module

URL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_ac\\_p.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_ac_p.pdf)

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

- Read the following sections of the Case Tutorial chapter and identify the foundational concept(s) applied in each of the calculations shown (i.e. the conceptual rational for each calculation):
  - Example: measuring parallel current phase shift
- Answer all points of the following questions found in the learning module:
  - “Parallel RL impedances” found in the Quantitative Reasoning section of the Questions chapter
  - “Parallel RC impedances” found in the Quantitative Reasoning section of the Questions chapter
  - “VIZ table for parallel RC circuit” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 10 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: RC networks powered by 60 Hz source
  - Build a simple parallel resistor-capacitor network and power it with low-voltage AC from the secondary winding of a step-down transformer energized by 120 VAC line power, then predict and measure all currents
  - Use an oscilloscope to measure phase shift between any two currents in the circuit (e.g. phase shift between  $I_{source}$  and  $I_R$ , between  $I_{source}$  and  $I_C$ , between  $I_R$  and  $I_C$ )
  - Use series or parallel networks of identical resistors instead of a single resistor in this same circuit, then re-calculate and re-measure AC voltages and voltage phase shifts
  - Use series or parallel networks of identical capacitors instead of a single capacitor in this same circuit, then re-calculate and re-measure AC voltages and voltage phase shifts
  - Draw phasor diagrams to accompany all calculations, showing each quantity represented as a vector (note that vectors stack tip-to-tail only for electrical quantities known to *add* in this type of network)
- Concept: (review) current divider circuit troubleshooting
  - Use the **tshoot** circuit simulation program to diagnose faults in a current divider circuit (Circuit #002) consisting of a current source, toggle switch, and three parallel-connected resistors

## Session 18

**Source text** – *Resonance* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Answer all points of the following question found in the learning module:
  - “Series LC circuit calculations” found in the Quantitative Reasoning section of the Questions chapter
  - “Parallel LC circuit calculations” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 100 k $\Omega$  for the best results
- ☐ Recommendation: avoid using power transformer windings as inductors, as these often contain significant parasitic capacitance that may cause self-resonance
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: series resonance
  - Choose capacitor and inductor values that should resonate together at some audio frequency within the range of your signal generator, then construct a simple series network using these two components
  - Energize this network using a variable-frequency signal generator and empirically determine when it reaches a condition of resonance (note: an oscilloscope is the ideal instrument to use, rather than a DMM, given the frequency limitations of most DMMs)

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

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

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

- Read the following sections of the Full Tutorial chapter:
  - Composition of light
  - Fourier's Theorem
  - Time vs. frequency in circuits
  - Time-frequency relationships
- Read the following section of the Historical References chapter:
  - Vibrating-reed meters as spectrum analyzers
- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - What is Fourier's Theorem?
  - What is a "harmonic" frequency?
  - What is the relationship between frequency and period for a wave?
  - What type of instrument do we use to measure harmonics in a circuit?
- Answer all points of the following questions found in the learning module:
  - "Harmonics of 60 Hz" found in the Quantitative Reasoning section of the Questions chapter
  - "Even versus odd harmonics" found in the Quantitative Reasoning section of the Questions chapter
  - "Amplifier test" found in the Conceptual Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to "make sense" of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: Line power harmonics
  - Use a digital oscilloscope with spectrum-analyzer capability (hint: this is often included as a "math" function using the Fast Fourier Transform algorithm) to measure low voltage at the secondary winding of a transformer powered by 120 VAC line power, identifying each harmonic present in that voltage waveform
- Concept: 555 astable timer harmonics
  - Build an astable (oscillator) circuit using a 555 timer IC, then use a digital oscilloscope to analyze the spectrum of its output signal, identifying each harmonic present in that voltage waveform
  - Alter the oscillator's fundamental frequency, use an oscilloscope in standard time-domain mode to measure the new signal frequency, then predict and measure the resulting harmonics

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

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

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

- Read the following sections of the Full Tutorial chapter:  
→ Applications for frequency-domain analysis
- Read the following sections of the Case Tutorial chapter:  
→ Example: triangle versus sine AC sources
- Read the following sections of the Derivations and Technical References chapter:  
→ Timbre  
→ Fourier series for common waveforms
- Answer the following questions to the best of your ability, referencing the tutorial in each case:  
→ Identify some practical uses for frequency-domain measurements  
→ Use frequency-domain terms to explain why different types of musical instruments have distinctive sounds  
→ Show how the calculated values in the Case Tutorial section (Example: triangle versus sine AC sources) could be calculated from the given circuit values, assuming an oscillator output voltage of 231.6 mVAC (RMS)

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: signal generator harmonics  
→ Connect a digital oscilloscope to a signal generator outputting square waves, activate its FFT math function to view the signal spectrum, and then identify the harmonics present in that square-wave signal ; compare the amplitudes of each harmonic against the Fourier Series equation for a perfect square wave  
→ Do the same, except for the triangle-wave output of the signal generator  
→ Do the same, except for the PWM output of the signal generator, noting the change in the signal’s spectrum as the PWM duty cycle is increased and decreased
- Concept: RC networks powered by signal generator  
→ Build a simple series resistor-capacitor network and power it with a low-frequency sine-wave or triangle-wave output of a signal generator (sine wave is ideal, but triangle wave gives approximate results), reading component voltages using a multimeter  
→ Build a simple series resistor-capacitor network and power it with the triangle-wave or square-wave output of a signal generator, reading same-harmonic component voltages using an oscilloscope with high-resolution FFT capability (e.g. read source voltage first-harmonic, and compare R and C first-harmonic voltages too; then do the same with 3rd harmonic; then do the same with 5th harmonic; etc.)

file wte\_0065



## Session 21

**Source text** – *Elementary Filter Circuits* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Signal separation
  - Reactive filtering
  - Bode plots
  - LC resonant filters
  - Summary of filter types
  - Filtering complex signals
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Explain what a “filter” network does and how it works
  - Identify the four basic types of filter network
  - Explain how to identify the type of filter network using the “limiting cases” problem-solving technique
- Answer all points of the following question(s) found in the learning module:
  - “Filter type and cutoff identifications” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between  $1\text{ k}\Omega$  and  $100\text{ k}\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: low-pass RC filter network
  - Build a low-pass filter network using a  $1.5\text{ k}\Omega$  resistor and a  $0.1\text{ }\mu\text{F}$  capacitor
  - Calculate this filter network’s cutoff frequency
  - Empirically test for cutoff at that frequency using an oscilloscope to compare input and output voltages
- Concept: high-pass RC filter network
  - Build a high-pass filter network using a  $1.5\text{ k}\Omega$  resistor and a  $0.1\text{ }\mu\text{F}$  capacitor
  - Calculate this filter network’s cutoff frequency
  - Empirically test for cutoff at that frequency using an oscilloscope to compare input and output voltages

file wte\_0066

Source text – *Elementary Filter Circuits* learning moduleURL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_filters.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_filters.pdf)

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

- Read the following sections of the Case Tutorial chapter:
  - Example: RC filter design
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What does “cutoff” mean for an ideal filter network?
  - What does “cutoff” mean for a real filter network?
  - Describe in your own words how we may select components when designing simple filter networks; what are the constraints we must be aware of, and how do we select the best component values for the application?
- Answer all points of the following question(s) found in the learning module:
  - “Designing simple RC low-pass and high-pass filters” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- ☐ Recommendation: all  $R$  and  $X$  values should be between 1 k $\Omega$  and 100 k $\Omega$  for the best results
- ☐ Caution: use must use *non-polarized* capacitors on all AC circuits!
- Concept: designing a low-pass RC filter network
  - The instructor will provide an arbitrary cutoff frequency and minimum/maximum input impedance range
  - You design this circuit using available components
  - Empirically test for cutoff at that frequency using an oscilloscope to compare input and output voltages
- Concept: designing a high-pass RC filter network
  - The instructor will provide an arbitrary cutoff frequency and minimum/maximum input impedance range
  - You design this circuit using available components
  - Empirically test for cutoff at that frequency using an oscilloscope to compare input and output voltages
- Concept: filter circuit troubleshooting
  - Use the `tshoot` circuit simulation program to diagnose faults in a passive filter circuit (Circuit #010) consisting of a signal generator, resistor, inductor, and capacitor

file wte\_0068

## Session 23

In today's session we will spend the entire time practicing the analysis and diagnosis of faults in circuits, also known as "troubleshooting". Not only is this a highly valuable skill to develop, but it also provides excellent opportunity to apply foundational concepts such as the effects of opens and shorts, Ohm's Law, Kirchhoff's Laws, etc. Several options exist for troubleshooting practice, which the instructor may select at will:

### Predicting consequences of faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, choose at random different faults that could be placed within this circuit (e.g. wires broken open, components failing open, components failing shorted) and predict how each of these faults will impact voltages and currents throughout the circuit. Your instructor will advise which faults are safe to introduce, versus which may lead to component damage or safety hazard(s). After making your predictions, introduce the (safe) fault and then use test equipment to verify whether or not your predictions were correct.

### Identifying hidden faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, identify specific points within the schematic diagram useful as "test points" between which you may take voltage measurements. If in doubt, simply include one test point for each and every electrically distinct point in the circuit. Then, connect long wires from numbered terminals on a terminal block to these test points, so each test point may be accessed for voltage measurement some distance from the breadboard. Your instructor will have you exit the room, place a fault in the breadboarded circuit, then cover up the breadboard with a box or cloth rag so the fault cannot be identified by visual inspection. Upon returning to the room, your task will be to identify the location and nature of the fault solely by taking voltage measurements between those numbered terminals, with the schematic diagram being your "road map" to the circuit.

### Using TSHOOT

A computer simulation program named TSHOOT exists for troubleshooting practice on simple circuits. It simulates all the steps described above for identifying hidden faults on a breadboarded circuit, but without the need for a physical circuit, a terminal block, or real test equipment. This program was developed for Unix-like operating systems, which means it runs natively on Linux or Apple PCs but requires WSL (Windows Subsystem for Linux) on Microsoft Windows PCs. 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`

Finally, we will brainstorm topics for the next session's "whiteboard interviews", where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.

## Session 24

Today's class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each "whiteboard interview" is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is "fair game" for these challenges, and together we will brainstorm possible topics during the previous session.

During your "interview" the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

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 real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

## Session 25

**Source text** – *Bipolar Junction Transistors* learning module

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

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

- Read the Simplified Tutorial chapter in its entirety and summarize the properties of bipolar junction transistors (BJTs).
- Identify the necessary conditions to turn on a “NPN” type of bipolar junction transistor.
- Identify the necessary conditions to turn on a “PNP” type of bipolar junction transistor.

**Source text** – *Field-Effect Transistors* learning module

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

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

- Read the Simplified Tutorial chapter in its entirety and summarize the properties of field-effect transistors.
- Identify the necessary conditions to turn on an “N-channel” enhancement-type MOSFET.
- Identify the necessary conditions to turn on an “P-channel” enhancement-type MOSFET.
- How do the other types of FETs behave, compared to the enhancement-type MOSFET?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors no smaller than 1 k $\Omega$  and no larger than 100 k $\Omega$  for the best results
- Concept: BJT-controlled lamp
  - Build a circuit using a bipolar junction transistor to control the energization of a lamp or DC motor, using a pushbutton switch to activate the transistor
  - Measure the amount of current controlled by the transistor, versus the amount of current needed to control the transistor
- Concept: MOSFET-controlled lamp
  - Build a circuit using a metal-oxide semiconductor field-effect transistor to control the energization of a lamp or DC motor, using a pushbutton switch to activate the transistor
  - Measure the amount of current controlled by the transistor, versus the amount of current needed to control the transistor

file wte\_0069

Source text – *Semiconductor Logic Gates* learning moduleURL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_logicgates.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_logicgates.pdf)

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

- Read the following sections of the Tutorial chapter:
  - Logic function review
  - Bicycle headlamp alarm
  - TTL versus CMOS logic
  - Logic levels
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What conditions are necessary to turn on a BJT?
  - What conditions are necessary to turn on a MOSFET?
  - Explain in your own words how the bicycle headlamp alarm system described in the Tutorial was designed and how it functions
- Answer all points of the following question found in the learning module:
  - “Diode-resistor logic gates” found in the Conceptual Reasoning section of the Questions chapter
  - “Malfunctioning security alarm system” found in the Diagnostic Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Recommendation: Texas Instruments’ datasheets tend to be very high-quality, so it’s often a good strategy to include “**ti**” in the web search engine string, or just go to **ti.com** and search on that site
- Concept: three-terminal regulator
  - Consult a datasheet for a model 7805 three-terminal voltage regulator, then build a demonstration circuit showing how it regulates a higher DC voltage down to 5.0 Volts suitable for powering TTL logic gates
- Concept: logic gate functions
  - Demonstrate a NOT function using an IC logic gate and an LED to reveal the gate’s output state
  - Demonstrate a two-input AND function using an IC logic gate and an LED to reveal the gate’s output state
  - Demonstrate a two-input OR function using an IC logic gate and an LED to reveal the gate’s output state
  - Demonstrate a two-input XOR function using an IC logic gate and an LED to reveal the gate’s output state

file wte\_0070

**Source text** – *Semiconductor Logic Gates* learning module

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

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

- Read the following sections of the Tutorial chapter:  
→ Comparators
- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts apply to semiconductor logic gates and to comparators.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:  
→ What input conditions are necessary to make a comparator's output go to a "high" state?  
→ What input conditions are necessary to make a comparator's output go to a "low" state?  
→ What are some practical applications for comparators?

During the scheduled session, you will work with your instructor to "make sense" of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

The balance of your class session time should be used to perform hands-on experiments exploring those same principles and strategies. Identify principles and/or circuit examples from the text that you would like to explore in more detail, formulate testable hypotheses, and then conduct experiments testing those hypotheses. *Note: some learning modules contain Case Tutorial chapters, which are another place to check for experimental ideas!*

For best results, please use resistors between 1 k $\Omega$  and 100 k $\Omega$  in size when constructing your experimental circuits. Resistors having resistance values outside of this range can result in problematic measurements or even excessive power dissipation in certain configurations! Also be sure to consult the datasheet for the semiconductor device(s) used in your experiments to ensure you will not damage these components with excessive voltage or current!

**Source text** – *Digital Numeration* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Numbers versus numeration
  - Unsigned integers
  - Shorthand representations of digital words
- Read the following section of the Programming References chapter:
  - Numeration formats in Python and C++
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What are some alternatives to our common decimal-based numeration system?
  - Why is binary the preferred numeration system for digital electronic circuits?
  - What practical purpose does octal or hexadecimal serve for human beings working with binary quantities?
- Read the “A binary resistance box” section of the Historical References chapter and answer the following questions:
  - Where do you find any properties of series networks applied to these “resistance box” designs?
  - Where do you find any properties of parallel networks applied to these “resistance box” designs?
- Answer all points of the following question found in the learning module:
  - “Binary to decimal and hex conversions” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

The balance of your class session time should be used to perform hands-on experiments exploring those same principles and strategies. Identify principles and/or circuit examples from the text that you would like to explore in more detail, formulate testable hypotheses, and then conduct experiments testing those hypotheses. *Note: some learning modules contain Case Tutorial chapters, which are another place to check for experimental ideas!*

Also, draft a list of teaching topics for the next (Teach-Back) session. Please (1) keep the topics as simple as possible, and only build in complexity *if* the learners prove their readiness; (2) DO NOT RUSH the learning process; (3) place learners in a role that is as *active* as possible so you will be able to tell how well they are learning. This same list will prove useful in identifying Whiteboard Interview topics you will be answering in a subsequent session!



Source text – *Combinational Logic* learning moduleURL – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_comblogic.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_comblogic.pdf)

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

- Read the following sections of the Tutorial chapter:
  - Logic functions
  - Universality
  - Combinational relay logic
  - Boolean expressions into circuits
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Explain how Boolean algebraic expressions may be used to describe logical functions
  - Compare and contrast semiconductor logic circuitry with relay logic circuitry
  - What does it mean for certain logic functions to be universal?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Recommendation: Texas Instruments’ datasheets tend to be very high-quality, so it’s often a good strategy to include “**ti**” in the web search engine string, or just go to **ti.com** and search on that site
- Concept: NAND gate universality
  - Demonstrate an AND function using nothing but NAND gates and an LED to reveal the final output state
  - Demonstrate an OR function using nothing but NAND gates and an LED to reveal the final output state
  - Demonstrate a NOR function using nothing but NAND gates and an LED to reveal the final output state
- Concept: gate-controlled motor circuit troubleshooting
  - Use the **tshoot** circuit simulation program to diagnose faults in a logic gate-controlled motor circuit (Circuit #009) consisting of a voltage source, two toggle switches, three TTL gates, a MOSFET, a relay, and a motor

**Source text** – *Combinational Logic* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Truth tables into circuits
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Explain how each of the example circuits shown in the Case Tutorial chapter sections (“Example: gate circuits from 4-input truth tables” and “Example: ladder logic circuits from 4-input truth tables”) were derived from their respective truth tables

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Recommendation: Texas Instruments’ datasheets tend to be very high-quality, so it’s often a good strategy to include “**ti**” in the web search engine string, or just go to **ti.com** and search on that site
- Concept: gate circuit from a three-input truth table
  - The instructor will provide a random three-input truth table for each student
  - Derive a Boolean expression for your given truth table, using any method you prefer
  - Sketch a schematic diagram of logic gates to implement that Boolean expression
  - Build that logic gate circuit to fulfill the truth table, using an LED to reveal its final output state

## Session 31

**Source text** – *Multiplexers and Demultiplexers* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Steering digital signals
  - Multiplexer and demultiplexer construction
  - Multiplexing and demultiplexing words
  - Arbitrary logic functions
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What is the difference between multiplexing and demultiplexing?
  - What is the function of an “enable” or “strobe” input to a digital logic circuit?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Recommendation: Texas Instruments’ datasheets tend to be very high-quality, so it’s often a good strategy to include “**ti**” in the web search engine string, or just go to **ti.com** and search on that site
- Concept: mux-based logic circuit fulfilling a three-input truth table
  - The instructor will provide a random three-input truth table for each student
  - Sketch a schematic diagram of a multiplexer wired to implement that Boolean expression
  - Build that multiplexer circuit to fulfill the truth table, using an LED to reveal its final output state
- Concept: (review) gate-controlled motor circuit troubleshooting
  - Use the **tshoot** circuit simulation program to diagnose faults in a logic gate-controlled motor circuit (Circuit #009) consisting of a voltage source, two toggle switches, three TTL gates, a MOSFET, a relay, and a motor

**Source text** – *Latching Logic* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Latch circuits
  - Set-Reset latches
  - SR enabled latches and flip-flops
  - D-type latches and flip-flops
  - JK flip-flops
- Explain every change in output state for the example timing diagrams in each of these Case Tutorial sections:
  - Example: enabled SR latch timing diagram section
  - Example: enabled D latch timing diagram section
  - Example: SR flip-flop timing diagram section
  - Example: JK flip-flop timing diagram section
  - Example: D flip-flop timing diagram section

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Concept: JK flip-flop demonstration
  - Build a circuit where three pushbutton switches provide input signals for a JK flip-flop IC, and two LEDs provide output status indication
  - Demonstrate all states of a JK flip-flop
- Concept: motor controlled by a flip-flop
  - Expand upon the above circuit to control the state of a small electric motor using a JK flip-flop, using a transistor to interpose between the flip-flop IC’s output and the relatively high-current motor

## Session 33

**Source text** – *Shift Registers* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Answer all points of the following question(s) found in the learning module:
  - “Timing diagram for a simple shift register” found in the Conceptual Reasoning section of the Questions chapter
  - “Timing diagram for another simple shift register” found in the Conceptual Reasoning section of the Questions chapter
  - “Timing diagram for yet another simple shift register” found in the Conceptual Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Concept: shift register from D-type flip-flops
  - Design a simple shift register using multiple D-type flip-flops packaged within a single integrated circuit (IC)
  - Build this circuit, and demonstrate its functionality using pushbuttons to provide all the input signals

## Session 34

**Source text** – *Digital Counters* learning module

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

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

- Read the Simplified Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to less than 20 mA each (typical full-brightness) in order to remain within typical logic gate output current limits as specified in datasheets
- Concept: 555-based clock source
  - Build an astable 555 timer circuit to generate a slow “clock” pulse (e.g. approximately 1 Hz) to drive some counter circuits
- Concept: 4-bit binary counter
  - Build a 4-bit binary counter circuit using a single counter IC connected to four LEDs (with appropriate current-limiting resistors) to show the count state
  - Demonstrate all the functions of this counter circuit
- Concept: 8-bit binary counter
  - Combine two 4-bit counters to create an 8-bit counter, referencing the counter’s datasheet to learn exactly how to cascade them
  - Demonstrate all the functions of this counter circuit

## Session 35

In today's session we will spend the entire time practicing the analysis and diagnosis of faults in circuits, also known as "troubleshooting". Not only is this a highly valuable skill to develop, but it also provides excellent opportunity to apply foundational concepts such as the effects of opens and shorts, Ohm's Law, Kirchhoff's Laws, etc. Several options exist for troubleshooting practice, which the instructor may select at will:

### Predicting consequences of faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, choose at random different faults that could be placed within this circuit (e.g. wires broken open, components failing open, components failing shorted) and predict how each of these faults will impact voltages and currents throughout the circuit. Your instructor will advise which faults are safe to introduce, versus which may lead to component damage or safety hazard(s). After making your predictions, introduce the (safe) fault and then use test equipment to verify whether or not your predictions were correct.

### Identifying hidden faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, identify specific points within the schematic diagram useful as "test points" between which you may take voltage measurements. If in doubt, simply include one test point for each and every electrically distinct point in the circuit. Then, connect long wires from numbered terminals on a terminal block to these test points, so each test point may be accessed for voltage measurement some distance from the breadboard. Your instructor will have you exit the room, place a fault in the breadboarded circuit, then cover up the breadboard with a box or cloth rag so the fault cannot be identified by visual inspection. Upon returning to the room, your task will be to identify the location and nature of the fault solely by taking voltage measurements between those numbered terminals, with the schematic diagram being your "road map" to the circuit.

### Using TSHOOT

A computer simulation program named TSHOOT exists for troubleshooting practice on simple circuits. It simulates all the steps described above for identifying hidden faults on a breadboarded circuit, but without the need for a physical circuit, a terminal block, or real test equipment. This program was developed for Unix-like operating systems, which means it runs natively on Linux or Apple PCs but requires WSL (Windows Subsystem for Linux) on Microsoft Windows PCs. 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`

Finally, we will brainstorm topics for the next session's "whiteboard interviews", where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.

## Session 36

Today's class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each "whiteboard interview" is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is "fair game" for these challenges, and together we will brainstorm possible topics during the previous session.

During your "interview" the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

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 real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.



**Source text** – *Programmable Control Devices* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Microcontrollers and PLCs
  - Logical AND function
  - Logical OR function
  - Logical NOT function
- Read the following sections of the Case Tutorial chapter:
  - Example: Arduino 3-input logic functions
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How do microcontrollers differ from PLCs in form?
  - How do microcontrollers differ from PLCs in function?
  - How do microcontrollers differ from PLCs in terms of programming languages?
  - What is the “normal” status of a switch contact?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use the power supplied to the Arduino by the USB cable, rather than connect an external battery
- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to a few milliAmperes each (typical full-brightness is 20 mA) in order to not over-burden the microcontroller output pins
- Concept: program an Arduino to perform basic logic functions
  - Two-input AND
  - Two-input OR
  - NOT
- Concept: program a PLC to perform basic logic functions
  - Two-input AND
  - Two-input OR
  - NOT

**Source text** – *Programmable Control Devices* learning module

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

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

- Read the following sections of the Case Tutorial chapter:
  - [Example: Arduino SOP truth table implementation](#)
  - [Example: Arduino NSOP truth table implementation](#)
- Answer the following questions to the best of your ability:
  - How do we design a logic gate circuit to implement a given truth table?
  - How do we design a relay logic circuit to implement a given truth table?
  - How do we program a microcontroller to implement a given truth table?
  - How do we program a PLC to implement a given truth table?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use the power supplied to the Arduino by the USB cable, rather than connect an external battery
- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to a few milliAmperes each (typical full-brightness is 20 mA) in order to not over-burden the microcontroller output pins
- Concept: program an Arduino to implement arbitrary truth tables
- Concept: program a PLC to implement arbitrary truth tables
- Concept: program a device to implement a truth table for some practical application
  - e.g. two-out-of-three redundant safety system
  - e.g. three-out-of-four redundant safety system

**Source text** – *Programmable Control Devices* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Off-delay timer function
  - On-delay timer function
- Read the following sections of the Case Tutorial chapter:
  - Example: Arduino off-delay timer
  - Example: Arduino on-delay timer
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How does an “off-delay” function differ from an “on-delay” function?
  - What is a routine in a computer program, also known as a subroutine or a function?
  - Identify multiple ways to implement time-delay functions using a microcontroller
  - Explain how you could calculate the amount of time delay provided by a logic gate with a resistor-capacitor timing network connected to the gate’s input

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use the power supplied to the Arduino by the USB cable, rather than connect an external battery
- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to a few milliAmperes each (typical full-brightness is 20 mA) in order to not over-burden the microcontroller output pins
- Concept: program an Arduino to start and stop a motor using pushbutton inputs
- Concept: program a PLC to start and stop a motor using pushbutton inputs
- Concept: program a device to start and stop a motor using pushbutton inputs, automatically shutting the motor off after a set period of time

**Source text** – *Digital Codes* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Read the following section of the Historical References chapter:
  - Ancient digital text code
- Answer all points of the following question(s) found in the learning module:
  - “Morse-coded message” found in the Conceptual Reasoning section of the Questions chapter
  - “ASCII-coded message” found in the Conceptual Reasoning section of the Questions chapter
  - “Using Python to convert between ASCII and hexadecimal” found in the Quantitative Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: file examination
  - Use a text editor (e.g. Notepad++) to create a few plain-text files containing any text data you wish
  - Add the hex editor plugin to Notepad++ and then use that to examine the contents of plain-text files you create
  - Use hex editor plugin to Notepad++ to examine the contents of files other than plain-text (e.g. Word documents, PDF documents, Excel spreadsheets, etc.)
- Concept: (review) loaded voltage divider circuit troubleshooting
  - Use the `tshoot` circuit simulation program to diagnose faults in a loaded voltage divider circuit (Circuit #004) consisting of a voltage source, two toggle switches, and five resistors

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

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

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

- Read the following sections of the Tutorial chapter:
  - Serial communication principles
  - Physical encoding of bits
  - Communication speed
  - Data frames
  - Parity
  - Frame check sequences
- Answer all points of the following question(s) found in the learning module:
  - “Serial data stream decoding” found in the Conceptual Reasoning section of the Questions chapter
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What are some different ways we may encode digital bits of information as electrical signals?
  - What kinds of auxiliary information needs to be communicated in a serial system besides the data itself?
  - How are streams of serial data synchronized for reliable reception?
  - What are some of the possible interpretational problems when communicating serially?
  - How do parity bits work to test for corruption of data?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Recommendation: limit LED currents to a few milliAmperes each (typical full-brightness is 20 mA) in order to not over-burden the microcontroller output pins
- Concept: program an Arduino to transmit a pre-programmed message in Morse code

Source text – *Serial Data Communication* learning module

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

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

- Read the following sections of the Tutorial chapter:
  - Flow control
  - Channel arbitration
  - The OSI Reference Model
- Answer all points of the following question(s) found in the learning module:
  - “EIA/TIA-232 data frames of ASCII characters” found in the Conceptual Reasoning section of the Questions chapter
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How could you explain each type of channel arbitration protocol by analogy to human conversations? (e.g. “*Master-Slave would be like three people in a group who . . .*”)
  - What is “flow control” and why is it necessary in some applications but not in others?
  - How does the OSI Reference Model relate to different communication systems?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use a potentiometer between 10 k $\Omega$  and 100 k $\Omega$  in value to form an adjustable voltage divider for the analog input signal
- Concept: program an Arduino to transmit serial data representing the “count” value of one of its analog inputs
  - Use the Serial Monitor to display the result(s)
  - Use a digital oscilloscope to capture that serial data as it is output at the “TX” pin of the Arduino

**Source text** – *EIA/TIA-232, 422, and 485 Serial Networks* learning module

**URL** – [https://ibiblio.org/kuphaldt/socratic/model/mod\\_232\\_422\\_485.pdf](https://ibiblio.org/kuphaldt/socratic/model/mod_232_422_485.pdf)

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

- Read the following section of the Tutorial chapter:  
→ EIA/TIA-232
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What are the minimum voltage levels specified in EIA/TIA-232 for “mark” and “space” states?
  - What is “flow control” and how is it implemented in EIA/TIA-232?
  - What is a “null modem” cable and when must we use one?
  - How fast may an EIA/TIA-232 network communicate?
  - What is a “DTE” device, versus a “DCE” device?

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Recommendation: use a voltage source known to be stable over time (e.g. a battery, instead of a solar panel)
- Recommendation: use resistors between 10 k $\Omega$  and 100 k $\Omega$  for all pullup and pulldown applications
- Concept: PC-to-PC serial communication
  - Connect two personal computers together using 9-pin serial cables, and using terminal software (e.g. termite, BlueTerm) to send text messages back and forth
- Concept: EIA/TIA-232 voltage level shifting
  - Connect an EIA/TIA-232 serial transceiver IC to an Arduino to convert the TTL-level serial data into standard EIA/TIA-232 “mark” and “space” voltage levels suitable for reception by a personal computer
  - Connect a personal computer to the IC’s output so it may receive the serial data from the Arduino microcontroller

**Source text** – *Ethernet Networks* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text
- Read the following section of the Derivations and Technical References chapter:
  - Hash algorithms
- Answer all points of the following question found in the learning module:
  - “Arbitration methods” found in the Conceptual Reasoning section of the Questions chapter

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: hash algorithms
  - Using the **nano** text editor in WSL, create a simple text file
  - Run a hash algorithm on that newly-created file, then modify the text file and re-run the hash algorithm and compare the results
  - Email that file to a classmate along with the correct hash, and let them check it upon receipt to see if the hash still agrees
- Concept: Ethernet configuration on PC
  - In a Windows command terminal (**cmd** or **PowerShell**), run **ipconfig** to determine the Ethernet port settings and MAC address
- Concept: WireShark setup
  - Start up the **WireShark** application on your PC and use it to monitor communications on your Wi-Fi port
  - Analyze several captured messages to identify the Ethernet frame data therein (e.g. source and destination addresses)



## Session 45

**Source text** – *Internet Protocols* learning module

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

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

- Read the Tutorial chapter in its entirety.
  - Answer at least *three* of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: WireShark setup
  - Run `ipconfig` on a Windows terminal (e.g. `Powershell`) to determine the IP address assigned to your computer by the Wi-Fi router; get the IP addresses of your classmates and share yours with them
  - Start up the `WireShark` application on your PC and use it to monitor communications on your Wi-Fi port
  - Choose several messages and one-by-one analyze their contents to see all the data contained therein
  - Identify where encapsulation is taking place in those messages
- Concept: Monitor ping messages
  - Set up a filter in `WireShark` to screen out every message except for those coming from or going to a classmate’s computer, using the filter command `ip.addr == ????.????.????.??? where the question-marks represent numerals of a classmate’s IP address`
  - Send “ping” messages to that classmate and monitor the content of those messages using `WireShark`
- Concept: Monitor UDP text message communication
  - Start up `SEL BlueTerm` software and configure it for a target IP address and port number on a classmate’s computer, noting your own (local) port number
  - Configure `BlueTerm` to use UDP rather than TCP
  - Send text messages back and forth to a designated classmate using UDP
  - Set up a filter in `WireShark` to screen out every message except for those coming from or going to a classmate’s computer, using the filter command `ip.addr == ????.????.????.??? where the question-marks represent numerals of that classmate’s IP address`
  - Note the captured data in `WireShark` resulting from text messages sent and received, then analyze those messages’ content

## Session 46

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

- Read the “Getting Started” section of the Instruction Manual for a model SEL-751 protective relay (available for download from [www.selinc.com](http://www.selinc.com)).
- Research ASCII commands used to monitor and configure an SEL model 751 protective relay by consulting the Instruction Manual for that relay (available for download from [www.selinc.com](http://www.selinc.com)).
- Answer the following questions to the best of your ability, referencing the Instruction Manual in each case:
  - Which command returns a “help” list of commands you can use with this relay?
  - Which command(s) allow(s) you to view or set the calendar date stored in the relay?
  - Which command displays “metered” quantities detected by the relay?
  - Which command shows various settings of the relay?
  - Which commands relate to settings or control of the relay’s Ethernet port?
  - Which commands are used to escalate your privileges in the relay to be able to make increasingly critical edits to its settings?
  - Which commands are used to manually open or close a circuit breaker connected to the relay?
  - Identify pin functions for the DE-9 serial connector, and determine whether the meter is a DTE or DCE device.

During the scheduled session, you will work with your instructor to “make sense” of the principles and strategies presented in the text:

- *Explain what you learned to the instructor*
- *Review your answers to the assigned questions*
- *Ask questions and receive clarification*

You will also work with your instructor to perform experiments exploring those same principles and strategies. Suggested experiments include:

- Concept: Use **AcSELeator** software to communicate with an SEL-751 protective relay
  - Execute the commands referenced in the preparatory work for this session
- Concept: Use **BlueTerm** software to communicate with an SEL-751 protective relay
  - Execute the commands referenced in the preparatory work for this session
- Concept: Program an Arduino to transmit ASCII commands appropriate for this relay, and then connect it to the relay via an RS-232 transceiver IC to test

## Session 47

In today's session we will spend the entire time practicing the analysis and diagnosis of faults in circuits, also known as "troubleshooting". Not only is this a highly valuable skill to develop, but it also provides excellent opportunity to apply foundational concepts such as the effects of opens and shorts, Ohm's Law, Kirchhoff's Laws, etc. Several options exist for troubleshooting practice, which the instructor may select at will:

### Predicting consequences of faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, choose at random different faults that could be placed within this circuit (e.g. wires broken open, components failing open, components failing shorted) and predict how each of these faults will impact voltages and currents throughout the circuit. Your instructor will advise which faults are safe to introduce, versus which may lead to component damage or safety hazard(s). After making your predictions, introduce the (safe) fault and then use test equipment to verify whether or not your predictions were correct.

### Identifying hidden faults

First, sketch a schematic diagram for a circuit embodying concepts previously learned, and construct that circuit on a breadboard. Next, identify specific points within the schematic diagram useful as "test points" between which you may take voltage measurements. If in doubt, simply include one test point for each and every electrically distinct point in the circuit. Then, connect long wires from numbered terminals on a terminal block to these test points, so each test point may be accessed for voltage measurement some distance from the breadboard. Your instructor will have you exit the room, place a fault in the breadboarded circuit, then cover up the breadboard with a box or cloth rag so the fault cannot be identified by visual inspection. Upon returning to the room, your task will be to identify the location and nature of the fault solely by taking voltage measurements between those numbered terminals, with the schematic diagram being your "road map" to the circuit.

### Using TSHOOT

A computer simulation program named TSHOOT exists for troubleshooting practice on simple circuits. It simulates all the steps described above for identifying hidden faults on a breadboarded circuit, but without the need for a physical circuit, a terminal block, or real test equipment. This program was developed for Unix-like operating systems, which means it runs natively on Linux or Apple PCs but requires WSL (Windows Subsystem for Linux) on Microsoft Windows PCs. 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`

Finally, we will brainstorm topics for the next session's "whiteboard interviews", where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.

## Session 48

Today's class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each "whiteboard interview" is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is "fair game" for these challenges, and together we will brainstorm possible topics during the previous session.

During your "interview" the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

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 real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

## *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