Course Outline for Engineering 43
ELECTRICAL CIRCUITS AND DEVICES

Catalog Description:
ENGR 43 - Electrical Circuits and Devices 4.00 units
Prerequisite: PHYS 4A (completed with a grade of "C" or higher) and , ENGR 25 (completed with a grade of "C" or higher)
Strongly Recommended: PHYS 4B (concurrent enrollment encouraged)

Grading Option: Letter Grade
Discipline:

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<th>Units</th>
<th>Lecture</th>
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<td>Laboratory</td>
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Prerequisite Skills:
None

Measurable Objectives:
Upon completion of this course, the student should be able to:
1. explain and apply the passive sign convention for current and voltage polarities;
2. describe and illustrate the operation of independent and dependent current/voltage sources;
3. state Ohm’s law of electrical resistance;
4. define Kirchoff’s Current Law of charge conservation;
5. define Kirchoff’s Voltage Law of energy conservation;
6. draw linear-circuit diagrams;
7. apply nodal analysis to solve linear-circuit problems for node voltages;
8. apply loop/mesh analysis to solve linear-circuit problems for branch currents;
9. employ source-superposition to solve linear-circuit problems for an output-voltage or output-current;
10. state the theorems of Thévenin and Norton;
11. evaluate linear-circuits to construct the Thévenin and Norton equivalent circuits;
12. apply the theorems of Norton and Thévenin to solve linear-circuit problems for an output-voltage or output-current;
13. assess, using the theorems of Norton and Thévenin, the exact circuit-load required for maximum power transfer to the load;
14. state the mathematical model for the ideal capacitor;
15. state the mathematical model for the ideal inductor;
16. formulate the circuit equivalents for resistors/capacitors/inductors combined in series or parallel connections;
17. evaluate the circuit response for first and second order, time-variant linear circuits, and produce a mathematical model for the transient response;
18. recall the proper mathematical form of a sinusoid;
19. express the phasor form of a steady-state sinusoidal voltage or current;
20. compute the frequency dependent value of the impedance for a capacitor or inductor;
21. solve steady-state sinusoidal linear circuits in the frequency domain for the phasor output-current or phasor output-voltage;
22. determine the transfer function for AC circuits;
23. perform power analysis for steady-state sinusoidal circuits;
24. simulate AC and DC circuit operation using computer-based simulation software such as SPICE or MultiSim;
25. calculate the bandwidth, B, and quality factor, Q, for bandpass and bandreject filtering circuits;
26. compute the number of bits needed to convert an analog voltage signal to a digital representation given the voltage-range and voltage-resolution (A-to-D Conversion);
27. compute the quantization error in percent produced when converting a digital representation to an analog voltage signal to given number of bits in the digital quantity (D-to-A Conversion);
32. convert numbers between decimal, binary, and other number bases;
33. construct Truth-Tables for the basic AND/NAND, OR/NOR, and Invertor logic gates;
34. use Boolean algebra to describe the operation of combinatorial-logic circuits constructed from the basic logic gates;
35. given an arbitrary combinatorial Truth-Table design a combinatorial-logic circuit that implements logic described by the Truth-Table;
36. construct Truth-Tables for the basic SR, D, and JK Flip-Flop sequential logic latches;
37. given an arbitrary sequential Truth-Table design a sequential-logic circuit that implements the sequence described by the Truth-Table;
38. use the Shockley equation to calculated diode-voltage and diode-current;
39. determine the operating-point voltage(s) for diode circuits using the ideal, offset, graphical load-line, and data sheet modeling;
40. draw half-wave and full-wave rectifier circuits;
41. sketch the cross-section view of standard PMOS and NMOS enhancement-mode Field Effect Transistors (FETs);
42. draw the circuit symbols for P and N enhancement-mode Field Effect Transistors;
43. use the graphical load-line technique to determine the operating point ("Q" point) for basic FET amplifiers;
44. use a small signal circuit model to calculate the small signal voltage gain of a common-source enhancement-mode FET amplifier;
45. draw, at the transistor level, CMOS logic gate schematics for the logic functions: inverter, NAND, NOR;
46. draw the transistor level CMOS logic gate schematic that implements an arbitrary combinatorial logic function as described by a Truth Table;
47. construct the Truth Table for an arbitrary transistor-level CMOS logic gate schematic;
48. list the characteristics of ideal operational amplifiers;
49. solve ideal operational amplifier DC-circuits for the output-voltage and/or output-gain;
50. determine the frequency response of ideal operational amplifier AC-circuits by sketching the Bode plot for the circuit;
51. design schematically ideal operational amplifier circuits to implement the mathematical operations of: summing, difference, integration, and differentiation;
52. operate standard electrical-engineering laboratory equipment to characterize the operation of electrical and electronic circuits
   a. oscilloscope
   b. electronic signal/function generator
   c. dc power supply
   d. digital multi-meter (DMM)
   e. resistance/inductance/capacitance meter (RLC meter)
   f. basic circuit components, such as:
      1) circuit board (bread board)
      2) resistor
      3) capacitor
      4) inductor
      5) semiconductor diode
      6) MOSFET/JT transistor
      7) operational amplifier;
53. Assemble/Fabricate and conduct lab experiments using standard electronic equipment including oscilloscopes, multimeters, RLC meters, signal/frequency generators, power supplies, and prototyping boards;
54. function with increased independence in laboratory, without extensive input on the part of the instructor: assemble and perform the experiments based on the instructions in the laboratory sheets, analyze laboratory data and present experimental results.

Course Content:

1. Basic quantities for electrical circuits: charge/current, potential
2. Linear circuits
   A. defined by the principle of superposition
   B. circuit diagrams
      a. nodes
      b. branches
      c. components
3. Circuit power balance: [power-dissipated] = [power-supplied]
4. Power Sources/Sinks - current and voltage
   A. Independent
   B. dependent
      a. current controlled
      b. voltage controlled
5. Passive Sign Conventions for current-direction vs. voltage-drop
6. Resistors
   A. mathematical model: \(v = ri\) (Ohm's Law)
   B. series and parallel combinations
7. Kirchoff's conservation laws for
   A. charge/current
   B. energy/voltage
8. Node analysis for unknown voltages using Kirchoff's current Law
   A. analytical solutions
   B. numerical analysis using MATLAB
9. Loop analysis for unknown currents using Kirchoff's voltage law
   A. analytical solutions
   B. numerical analysis using MATLAB
10. Superposition of independent voltage and current sources
11. Thévenin’s theorem for an equivalent circuit consisting of
    A. an independent voltage source
    B. a series resistance
12. Norton’s theorem for an equivalent consisting of
    A. an independent current source
    B. a parallel resistance
13. Maximum Load-Power Transfer analysis using Thévenin’s or Norton’s theorem
14. Capacitors
    A. mathematical model: \(i = C\frac{dv}{dt}\)
    B. series and parallel combinations
15. Inductors
    A. mathematical model: \(v = L\frac{di}{dt}\)
    B. series and parallel combinations
16. Operational amplifier resistor-capacitor circuits:
    A. ideal integrator
    B. ideal differentiator
17. Linear circuit transient response:
    A. first order: asymptotic exponential rise or decay
    B. second order
       a. over damped
18. AC steady state circuit analysis:
   A. review of sinusoids
   B. phasor notation for currents and voltages
      a. magnitude
      b. phase angle
   C. impedance and admittance
   D. circuit diagrams in the frequency (phasor) domain
   E. circuit analysis in the frequency (phasor) domain
      a. nodal
      b. loop
      c. superposition
      d. Thévenin
      e. Norton
   F. numerical analysis using MATLAB

19. AC and DC Schematic-Based computer-aided circuit-analysis tools such as: PSPICE, LTSPICE, NI Multisim;

20. Steady-State power analysis:
   A. calculating average power
   B. maximum average-power transfer to a load
   C. effective, or RMS, values for current and voltage
   D. power-factor and phase-angle
   E. complex power, $S$
      a. real (average) power, $P$
      b. reactive power, $Q$

21. RLC circuit variable-frequency response analysis
   A. Phasor analysis for transfer voltage/current gain, transfer impedance, transfer admittance
   B. Transfer Functions: poles and zeroes

22. Bode Magnitude & Phase Plots by hand
   A. decibels (dB) calculations for
      a. Power ratios
      b. Voltage or Current ratios
   B. 3 dB corner frequency
   C. ±20 dB per decade magnitude slope at the corner frequency
   D. ±45° per decade phase slope about the corner frequency

23. Computer Generated Bode Plots using MATLAB or Excel

24. Passive Electrical Frequency Filters
   A. Highpass
   B. Lowpass
   C. Bandpass
   D. Bandreject
   E. First and second order
   F. Natural/Center frequency
   G. Bandwidth
   H. Quality Factor
   I. Bode Plots

25. Binary, Decimal, Hexadecimal, Octal numbers
   A. Converting between the various number bases
   B. Arithmetic operations with binary numbers

26. Combinatorial Logic Circuits
   A. Symbols and Truth-Tables for basic gates:
      a. Invertor
      b. AND/NAND
      c. OR/NOR
      d. XOR/XNOR
   B. Boolean Algebra and DeMorgan’s Laws

27. Combinatorial Logic Design
   A. Sum of Products, minterms
   B. Product of Sums, maxterms

28. Sequential Logic Circuits
   A. Symbols and Truth/State Table for SR, D, JK Flip-Flop latches
   B. Timing and propagation-delay

29. Micro computers/controllers
   A. Architecture and organization in block-diagram form
   B. Types of memory
   C. Data buses
   D. Example instruction-sets and addressing-modes
   E. Finite State Machines

30. Basic Diode Characteristics
   A. $v_i$ curve
   B. Shockley equation
   C. Forward and Reverse bias
   D. Reverse/Avalanche breakdown

31. DC Diode circuit analysis
   A. Graphical Load-Line analysis
   B. Ideal-Diode Break-Point analysis

32. Diode rectifier circuits: half-wave, full-wave

33. Diode small-signal dynamic resistance

34. NMOS and PMOS Enhancement Mode Field Effect Transistors
   A. Physical structure in silicon
   B. Electrical Operating Regions in $v_i$
      a. Cut-off
      b. Triode
      c. Saturation
   C. Load-Line and Bias-Line Operating-Point Analysis
   D. Small Signal Equivalent for Common-Source and Source-Follower circuits
      a. Transconductance
      b. Drain Resistance
      c. Voltage gain
35. CMOS Logic Gates
   A. NMOS and PMOS FETs as complementary switches
   B. NMOS and PMOS FET schematics to implement basic combinatorial logic:
      a. Inverter
      b. NAND
   C. NOR
   D. Construct a Truth Table given a CMOS Logic circuit schematic
   E. Design of a CMOS logic circuit given a Truth Table
   F. Gate delay and timing
36. Ideal Operational Amplifier (OpAmp) circuit model
   A. Infinite input resistance
   B. Infinite voltage gain
   C. Zero output resistance
37. Basic OpAmp Circuits
   A. Voltage Follower (Unity Gain Buffer)
   B. Inverting (feedback) amplifier
   C. Noninverting (feedback) amplifier
38. OpAmp Mathematical-Operation Circuits
   A. Summing
   B. Difference
   C. Integration
   D. Differentiation
39. OpAmp Frequency Response
   A. Bode Plots
      a. Open-Loop
      b. Closed-Loop
      c. Full-Power Bandwidth
40. OpAmp Practical Limitations
   A. Output Voltage Swing
   B. Output Current Saturation
   C. Slew Rate (maximum dV/dt)

Course Content (Laboratory):

1. Laboratory exercises to reinforce the circuit concepts, formulas, analysis methods, and calculations presented in lecture/discussion
   A. Construct circuits using basic components, such as:
      a. circuit board (breadboard)
      b. resistors
      c. capacitors
      d. inductors
      e. diodes
      f. transistors
      g. operational amplifiers
      h. cables, leads, and jumper-wires
   B. Operate standard electrical engineering instruments:
      a. multichannel oscilloscope
      b. electrical signal/function generator
      c. dc power supply
      d. digital multi-meter (DMM)
   C. Use DMM and oscilloscope measurements to calculate secondary electrical quantities including:
      a. power supplied and dissipated (confirm power-balance)
      b. verify Ohm's law for resistors, and Shockley's equation for diodes
      c. verify multiple voltage-source superposition
      d. Thévenin equivalent: Voltage-Source, Series-Resistance
      e. inverting and noninverting operational amplifier circuit: Gain, Current/Voltage Saturation
      f. sinusoidal voltage-source driven RC, RL, and RLC circuit: frequency dependent quantities of impedance, current/voltage magnitude & phase
      g. AC frequency sweeps used to construct Bode Plots for various AC filters
      h. Time constants for transient operation of RL, RC, and RLC circuits
2. Laboratory use of computers to perform computer-aided simulation of AC & DC electrical circuits using SPICE-based software.
3. Practical Laboratory Examination wherein students
   A. Construct a sinusoidal voltage-source driven RLC circuit per an electrical schematic diagram
   B. Measure component values using the LCR meter
   C. Measure rms voltages and currents using the DMM
   D. Measure voltage amplitudes, and waveform time-shifts using the oscilloscope
   E. Calculate reactances from the DMM measurements
   F. Calculate Magnitudes and Phase-Angles from the oscilloscope measurements

Methods of Presentation

1. Lecture/Discussion
2. Formal lectures using PowerPoint and/or WhiteBoard presentations
3. Circuit Laboratory demonstrations
4. Computer demonstrations
5. Reading from the text
6. Laboratory use of computers
7. Class discussion of problems, solutions, and student's questions

Assignments and Methods of Evaluating Student Progress

1. Typical Assignments
   A. Read chapter 6 in the textbook on Frequency Response and Bode Plots.
   B. Complete exercises from the textbook, or those created by the instructor
      1) Use both nodal analysis and mesh analysis to find Vo in the DC circuit shown below. 2) Consider the switched (transient) electrical circuit shown at Right. Solve for the inductor current, i(t) for t > 0. Use MATLAB to Plot the response curve for i(t). 3) Find the output potential, VO for the DC OpAmp Circuit Shown Below. 4) For the CMOS Logic Gate circuit shown below: • Complete the Truth Table • Write a Boolean algebra equation for output Y in terms of the inputs A, B, and C • Draw an equivalent logic circuit using standard logic gates: INVERTOR, AND/NAND, OR/NOR 5) Express in BINARY, OCTAL, and HEXADECIMAL forms the decimal number 7824310
   C. Express in BINARY, OCTAL, and HEXADECIMAL forms the decimal number 7824310
   D. Consider the BandPass Filter Circuit Shown Below For this Circuit: • Calculate the: Resonant Frequency (f0), BandWidth (B), and quality factor, Q • SKETCH the Magnitude and Phase Bode Plots • Use SPICE software to simulate the circuit, and to produce a computer generated Bode Plot • Compare the Sketched and Computer-Generated Bode Plots. Comment the
relative accuracy of the sketch.

C. Complete Hands-On Laboratory Exercises designed by the instructor to reinforce the lecture material, and to develop electrical-measurement and electrical trouble-shooting skills. 1) Conduct the Laboratory Exercise on Thévenin equivalent Circuits as described in the laboratory instructions. Assemble the circuit shown on the next page, and then use the voltage-supply and digital multimeter to determine the Thévenin resistance by short-circuit current and open-circuit voltage, and by source deactivation. 2) Conduct the Laboratory Exercise on BandPass Filter Circuits as described in the laboratory instructions. Assemble the circuit shown below using the RLC meter to accurately measure the component values. Then use the function/signal generator and digital oscilloscope to perform an AC frequency sweep to determine the magnitude and phase-angle for the resistor voltage, VR. Use MATLAB to create Bode Plots for the VR magnitude and phase using the data generated in your experiment. GRAPHICALLY determine the BandWidth for this filter. Compare the experimental bandwidth to the bandwidth calculated using the RLC meter values. ANALYZE the trends shown in the plots, and comment on the physical CAUSE of the observed trends 3) Conduct the Laboratory Exercise on the NONinverting OpAmp Circuit as described in the laboratory instructions. Assemble the circuit shown below using the DMM to accurately measure the resistor values. Then use the DMM current and voltage functions to measure: i, I, V, VI, VR. Calculate the measured VO/Vi voltage-gain of the circuit and compare to the Ideal OpAmp calculations as demonstrated in Lecture. Does either the current or voltage output SATURATE under any circumstances? If so, which one(s).

2. Methods of Evaluating Student Progress
   A. Daily Reading-Completion Verification-Quizzes
   B. Weekly Homework Assignments
   C. Weekly Hands-on Laboratory Exercises
   D. Practical Laboratory Examination
   E. Written Midterm Examinations
   F. Written Final Examination

3. Student Learning Outcomes
   Upon completion of this course, the student should be able to:
   A. Analyze a Steady-state DIRECT Current circuit to determine unknown electrical quantities and/or responses.
   B. Analyze Steady-state ALTERNATING Current circuit
   C. Analyze Steady-state DC-RLC, AC-RLC, and Op-Amp circuits to calculate unknown electrical-potentials or electrical-currents using Kirchoff’s Current and/or Voltage Law, and the Ideal Op-Amp approximation
   D. Analyze Steady-state SWITCHED Transient circuits
   E. Given a transistor-level CMOS Logic Gate schematic:
   F. Laboratory Practicum to Demonstrate the ability to construct an AC sinusoidal electrical circuit and then use a DMM and Oscilloscope to measure circuit voltages & currents, and to calculate voltage amplitudes & phase-angles.
   G. Demonstrate the ability to construct an AC electrical circuit and then use a DMM and Oscilloscope to measure circuit voltages and currents

Textbooks (Typical):

Special Student Materials

Abbreviated Class Schedule Description:


Prerequisite: PHYS 4A (completed with a grade of "C" or higher) and, ENGR 25 (completed with a grade of "C" or higher)

Strongly Recommended: PHYS 4B (concurrent enrollment encouraged)