Syllabus - PH411 Analog and Digital Electronics

Concepts

This course, part of a three quarter sequence, presents the most basic concepts of electronics and the use of electronics for experimental physics and engineering applications. The development of experimental skills and analytical approaches to analyses of physical systems is integrated into the course. Students gain experience working with common laboratory instrumentation, learn how turn theory and diagrams into a functioning circuit and learn how to present experimental work and analysis in a concise report. Concepts from introductory physics courses and the paradigms courses are reinforced in the context of experimentation and analysis. Specific concepts include: electrostatic potential energy and work; conservation of charge; electromagnetic potentials, fields and currents; time-dependent electromagnetic phenomena; material responses to elecromagnetic fields; time-domain and frequency-domain analyses of physical systems; Fourier series and Fourier transforms; complex numbers - amplitude and phase; resonance in electromagnetic systems; positive and negative feedback in circuits; operational amplifiers; applications of operational amplifiers; statistical methods in data analyses.

Texts

- Required books:

  Introductory Electronics for Scientists and Engineers, by R. E .Simpson, ISBN 0205083773.

  PH411 Notes and Laboratory Experiments, W. M. Hetherington

- Useful books:

  The Art of Electronics and *Student Manual for the Art of Electronics* both by Horowitz and Hill.

Meeting Times

The lectures and laboratory sessions are organized coherently. Some lectures will discuss laboratory procedures and results, and some laboratory sessions will involve discussion of theoretical issues.

- Lectures: Monday and Wednesday at 9:00 in 149 Weniger
- Laboratory sessions: Tuesday and Thursday 9:00 - 10:20 in 302 Weniger, but the rooms will be open 8:00 - 11:50.

Instructors

- William M. Hetherington, Associate Professor of Physics

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- Nicholas Kuhta, Teaching Assitant

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Grading

- Laboratory reports, problems and quizzes = 66%, midterm examination = 12%, final examination = 21%. Class participation will also be taken into account for borderline grade decisions.
- Since the lectures and laboratory experiments assume understanding of all previous material, it is important that reports and problem sets be submitted on time. The policy concerning penalties for late reports will be discussed in class.

Schedule

Introduction

- Reading: Simpson Chapter 1.1-1.7
- Lecture Monday 26 Sept.

  Purpose of the course

  Basic electrostatic concepts : potential and field; potential energy - conservation of energy; battery as an ideal potential source; conversion of electrostatic potential energy to thermal energy in an object
- Laboratory session Tuesday 27 Sept: Introduction to the electronics laboratory; statistical analyses of measurements of resistance and power.

Resistance

- Reading: Simpson Chapter 1.1-1.7
- Lecture Wednesday 28 Sept.

  Continuous currents through objects: Material structure and the ability to conduct current, with examples; Relationship of current density to electric field - conductivity; Relationship of current to potential difference across an object - resistance; Relationship among conductivity, conductance, resistivity and resistance; Ohmic behavior of some objects over a specified range of potential difference; Non-Ohmic behavior of objects - diodes, thermal excitation of carriers and dielectric breakdown; Power dissipated in resistive objects - ohmic and non-ohmic .
- Laboratory session Thursday 29 Sept. - Lab 1: Resistance
- Reading: Simpson 1.8-1.14
- Lecture Monday 3 Oct.

  Kirchoff's Potential and Current Laws - conservation of energy and charge; inear algebraic solutions for complex circuits - Maple worksheet example.
- Laboratory session: Tuesday 4 Oct. - Continuation of Lab 1: Resistance.
- Lecture Wednesday 5 Oct.

  Thevenin equivalent circuits; Norton equivalent circuits; instrumental output resistance; instrumental input resistance.

- Laboratory session: Thursday 6 Oct. - Continuation of Lab 1: Resistance.
- Lecture Monday 10 Oct.

  Thevenin equivalent circuits; Norton equivalent circuits; instrumental output resistance; instrumental input resistance.

Laboratory Instrumentation

- Laboratory Session Tuesday Oct. 11 - Introduction to oscilloscopes, waveform generators and data acquisition

  Guided introduction to using the waveform generators and oscilloscopes; using the Marina application for data acquisition; experimental $I(V)$ measursement using a potential divider.

Capacitance and RC Circuits

- Reading: Simpson Chapter 2.1-2.4, 2.8-10
- Lecture Wednesday 12 Oct.

  Dielectric response of materials and capacitance; Time-domain analysis of the RC circuit.
- Laboratory session Thursday 13 Oct. - Lab 2: Capacitance and time-dependent behavior of RC circuits.
- Lecture Monday 17 Oct.

  Frequency-domain analysis of RC circuits; integrator circuit approximation; complex impedance; complex numbers
- Laboratory session: Tuesday 18 Oct. - Continuation of Lab 2
- Reading: Simpson Chapter 2.5, 2.7
- Lecture Wednesday 19 Oct.

  CR circuit - just the RC circuit measured differently; differentiating circuit approximation; analysis and complex impedance of the CR circuit
- Laboratory session Thursday 20 Oct. - Continuation of Lab 2
- Lecture Monday 24 Oct.

  HP and LP filters - physical analysis in the frequency domain; power dissipation; Bode plots; Effects of output and input capacitances; AC coupling.

Inductance and RL Circuits

- Reading: Simpson Chapter 2.11-13
- Lecture Monday 24 Oct.

  Introduction to inductors; physical reasoning and LR and RL circuits; Faraday's and Ampere's Laws and inductance.

- Laboratory session Tuesday 25 Oct. - Lab 3: Inductance and time-dependent behavior of LR circuits - parts 1 and 2.
- Lecture Wednesday 26 Oct.

  Time-domain analysis of RL circuits; frequency-domain analysis of RL circuit - complex impedance; HP and LP filters - physical analysis; filters in series - sharper cutoffs or crude bandpass filters; effects of output and input inductances; warning about the effects of inductors in circuits - large potentials are possible.
- Laboratory session Thursday 27 Oct. - Measuring the response function using a computer; continuation of Lab 3 - part 3.

RLC Circuits and Resonance

- Reading: Simpson Chapter 2.11-13
- Lecture Monday 31 Oct.

  RL lab measurements exhibit some "ringing" - why?; Time domain analysis of parallel lossless LC circuit - solve differential equation; Analogies to other physical systems - pendumlum, etc.; Real oscillator - resistive loss results in exponential decay of amplitude; Impulse current excitation vs. initial applied potential - initial magnetic energy vs. initial electrostatic energy; Analogy to impulse or initial displacement excitation of pendulum; Creating an impulse in the lab.
- Lab Session Tuesday 1 Nov. - Lab 4: Behavior of RLC circuits
- Lecture Wednesday 2 Nov.

  Lecture notes: RLC circuit analysis; The R+L||C circuit - physical reasoning; Parallel LC circuit - frequency-domain solution of two differential equations; Complex impedance analysis of parallel LC circuits; Bandpass filter and Quality factor.
- Lab Session Thursday 3 Nov. - Continuation of Lab 4: Behavior of RLC circuits
- Lecture Monday 7 Nov.

  The R+L+C circuit - physical reasoning; Series LC circuit - frequency-domain solution of the differential equation; Complex impedance analysis of series LC circuits; Notch filter and Quality factor; Fourier analysis of the square wave using the bandpass filter - the square wave as a Fourier series.
- Lab Session Tuesday 8 Nov. - Continuation of Lab 4: LC filters
- Lecture Wednesday 9 Nov. - Midterm
- Lab Session Thursday 10 Nov. - Fourier transforms with burst signals, load impedance vs. cable impedance, establishing a 50 Ohm load, transformers and mutual inductance.
- Lecture Monday 14 Nov. - Transformers and frequency-independent loads, power dissipation in general RLC circuits.

Introduction to Operational Amplifiers

- Reading: Simpson Chapter 7.1-2, 9.1, 9.4, 9.6-7
- Lecture Monday 14 Nov.

  General transformation of signals; Concept of a “black box” with ideal properties; Concept of feedback; The operational amplifier - difference amplifier; Significance of large open-loop gain; Opamp rules.
- Lab Session Tuesday 15 Nov. - Lab 5: Introduction to operational amplifiers
- Lecture Wednesday 16 Nov.

  Gain of an operational amplifier - inverting and noninverting. Non-idealities of op amps; Finite frequency response and the variation of gain and phase with frequency; Simulation program for op amp gain as a function of frequency; Slew rate and and distortion of waveforms;
- Lab Session Thursday 17 Nov. - Continuation of Lab 5: Introduction to operational amplifiers
- Lecture Monday 21 Nov.

  Input offset potential - manifestation and correction; Input bias current - analysis and correction for inverting and noninverting amplifiers, input resistance; Rejection of power supply variation - PSRR; Common mode signals and amplification - CMRR;
- Lab Session Tuesday 22 Nov. - Continuation of Lab 5: Introduction to operational amplifiers

Operational Amplifier Applications

- Lecture Wednesday 23 Nov.

  Transimpedance amplifier; Summing amplifier with inverting and non-inverting inputs; Baseline shift of time-varying signal using the summing amplifier; Digital to analog conversion using a summing amplifier;
- Lab Session Thursday 24 Nov. - Special Lab: Anatomy of a large bird
- Lecture Monday 28 Nov.

  Continuation of op amp applications material.
- Lab Session Tuesday 29 Nov. - Lab 6: Operational amplifier applications - summing and transimpedance amplifiers
- Lecture Wednesday 30 Nov.

  Course summary
- Lab Session Thursday 1 Dec. - Continuation of Lab 6: Operational amplifier applications

Final Examination

- Final exam will be given Tuesday 6 December at 6:00 PM in 149 Weniger