

# Teaching Circuits to New Generations of Engineers

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# Roadmap

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# Introduction

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- Understanding circuits is fundamental to electric engineering and continuing to offer courses in theory and applications of electric circuits to new generations of engineering students remains an important part of any engineering curriculum.
- Attracting new generations of students to circuits is a challenging task that calls for new approaches, methodologies, and projects that will appeal to current generations of both educators and students.
- Designing these new tools and making them freely available to educators is an important step in eliciting renewed interest in circuits.



# Motivation

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- Providing students with a solid theoretical background greatly improves their ability to solve a variety of practical engineering problems.
- National institutions have recognized the need for improving engineering education.
- Attracting the best students to engineering programs and eliciting their interest to circuits courses has been also subject of a number of ongoing debates over the past two decades.



# Engineering options

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- Current engineering programs offer a number of majors:
  - electronic
  - computer
  - bioengineers
  - mechatronics
- These programs may need circuits courses carefully tailored to fit a program's specific curricula.
- The “cookbook” approach may not be serving future electrical engineers well.
- Lectures, tutorials, and laboratories are often supplemented by software tools such as MATLAB and SPICE to enhance understating of the theory taught.



# Presentation styles and delivery

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- From blackboard to overhead projectors to PowerPoint slides and back to the whiteboard.

## Communication tools:

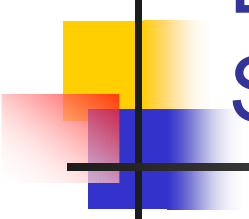
- web pages, online notes, electronic handouts, audio recordings of lectures, examples from industry, fun exercises and puzzles. And endless stream of email messages
- Presentation styles and delivery are often enhanced by good textbook supplements: master slides, tutorial problems, solution manuals).
- Ongoing demand for new tutorials, video-taped lectures, educational games, design kits, fun and motivational lectures, and online content.



# Course instructors

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- In many engineering departments, circuits courses are considered to be service courses.
- They are often taught by sessionals and instructors as a service to the department.
- These instructors are often unmotivated and can hardly generate students' enthusiasm.
- More senior faculty teaching circuits courses often have their research interests in areas not related to circuit theory and/or circuit design.
- Lack of industrial experience often deprives instructors from appreciating the importance of practical applications in engineering education.

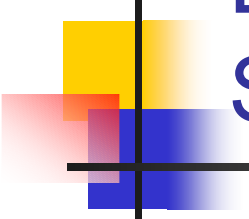


# Engineering program at Simon Fraser University

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- School of Engineering Science offers two classical undergraduate courses in electric circuits. These courses are offered to second and third year students.
- SFU follows trimester system (three terms per calendar year) and each term lasts thirteen weeks.
- There are weekly homework assignments and the midterm and final examinations.
- In addition to three-hour lectures per week, one-hour tutorials offered weekly for the two basic circuits courses deal with solving analytical problems.
- Both undergraduate courses have laboratory components and students are expected to submit written laboratory reports. The School follows the 24/7 open-laboratory model.





# Engineering program at Simon Fraser University

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- There is no required textbook. Several textbooks are recommended. A large number of textbooks and references related to filter design are made available through the University Library reserves.
- Occasionally, a course in nonlinear circuits is offered to senior undergraduate and graduate students as a special topics course.
- There are weekly homework assignments, two short midterm examinations, and a final research project.

# Laboratory



ISCAS 2011, Rio de Janeiro, May 17, 2011



# First course: Electric Circuits I

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- The first course in electric circuits deals with elementary concepts and analysis tools.
- The course pre-requisites are two first year physics courses and the course co-requisites are two second year mathematics courses.
- This course is a pre-requisites for undergraduate courses in electronic devices and microelectronics.



# First course: Electric Circuits I

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## Topics:

- **Circuit elements:** voltage sources, current sources, resistors, diodes, transistors.
- **Kirchhoff current (KCL) and voltage (KVL) laws**
- **Operational amplifiers (op-amps):** ideal models of opamps; inverting and non-inverting op-amps; the op-amp and a dependent source.
- **Circuit analysis techniques:** nodal and loop (mesh) analysis: linearity, superposition, and source transformations;
- **Thevenin and Norton theorems;** maximum power transfer.
- **First order circuits:** inductors and capacitors; response of RL and RC circuits.
- **Second order circuits:** series and parallel RLC circuits; step response.



# First course: Electric Circuits I

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- **Sinusoidal steady-state analysis:** sinusoidal response; phasor analysis; real, active, and complex power.
- **AC power:** power in time domain; power in sinusoidal steady state; average or real power; reactive power; summary of AC power in R, L, and C; exchange of energy between an inductor and a capacitor; complex power, apparent power, and power triangle; parallel-connected networks; power factor improvement; maximum power transfer.
- **Polyphase circuits:** introduction; two-phase systems; three-phase systems; wye and delta systems; phasor voltages; balanced delta-connected loads; balanced fourwire; wye-connected loads; equivalent wye and deltaconnections; single-line equivalent circuit for balanced three-phase loads; unbalanced delta-connected load; unbalanced wye-connected load; three phase power; power measurement.



# Electric Circuits I laboratories

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- *Lab bench orientation:*
  - Part 1, Power supply and digital multimeter
  - Part 2, Function generator and oscilloscope
- *Lab 1, KCL and KVL*
- *Lab 2, Op Amp*
- *Lab 3, RL and RC circuits.*
- *Lab 4, RLC circuits*
- *Lab 5, AM radio demo*



## Second course: Electric Circuits II

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- The second course in electric circuits is intended to enhance the knowledge of students in the area of electric circuits and to further develop their analytical skills.
- The course pre-requisite is the first course in electric circuits.

### Topics:

- **Analysis of circuits in the time domain:** review of differential equation analysis of linear circuits; treatment of initial conditions; zero state and zero input responses; properties of more general linear time invariant systems in continuous time; convolution, unit impulse response.



## Second course: Electric Circuits II

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- **Laplace transform** analysis of circuits: the Laplace transform and its inversion by partial fractions; properties: multiplication-convolution, differentiation, initial and final value theorems; circuits in the s-domain: transfer function, impedance, circuit reduction, initial conditions; series and parallel decompositions; pole-zero diagrams related to time domain behavior.
- **Frequency response, filters, and resonance**: frequency response; high-pass and low-pass networks; half-power frequencies; frequency response from pole-zero locations and Bode plots; bandpass filters and resonance; natural frequency and damping ratio. RLC series circuit; series resonance; quality factor; RLC parallel circuit; parallel resonance; practical LC parallel circuit; series-parallel conversions; locus diagrams.





# Electric Circuits II laboratory

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- **Filter design:** filter classes (Butterworth, Chebyshev); implementation diagrams, quadratic sections; state variable description; active filter implementation: Sallen-Key and state variable filters; other active filter configurations.
- **Mutual inductance and transformers:** mutual inductance; coupling coefficient; analysis of coupled coils; dot rule energy in a pair of coupled coils; conductively coupled equivalent circuits; linear transformer; ideal transformer; autotransformer; reflected impedance.
- **Two-Port networks:** terminals and ports, z-parameters; t-equivalent of reciprocal networks. y-parameters; pi-equivalent of reciprocal networks; applications of terminal characteristics; conversion between z and y parameters; h and g parameters; transmission parameters; interconnecting two-port networks; choice of parameter type.



# Electric Circuits II laboratory

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- The laboratory exercise deals with the design and implementation of an active filter.
- The students are asked to design a low pass filter for telephone speech signals that have bandwidth of 300–3,400 Hz.
- The filter is to be used to suppress interference by attenuating interference signals by at least 30 dB starting at 11 kHz.
- The telephone signal should not be attenuated more than 0.5 dB. Students are given the laboratory assignment and the instructions early in the trimester:



# Electric Circuits II laboratory

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## Design:

- Examine Butterworth and Chebyshev filter realizations that meet the specifications.
- Plot frequency responses using MATLAB. Select the most appropriate filter type, order, and filter parameters.
- Design the filter using Sallen-Key stages with an overall gain (output voltage/input voltage) in the range 2 to 3.
- Simulate your design using PSPICE.
- Build the filter circuit, test it, and compare its performance to the specifications and to PSPICE predictions.



# Electric Circuits II laboratory

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The kit with **parts** contains:

- quad op amp: TL074CP; various resistors (k $\Omega$  range); capacitors in the nF range: 22 nF caps, quantity 4; 10 nF caps, quantity 4; 3.3 nF caps, quantity 4; 1 nF caps, quantity 4; power supply isolation capacitors (0.1  $\mu$ F, quantity 4).

**Test measurements:**

- Input a sinusoidal wave of 2 V peak-to-peak and plot the frequency response (magnitude and phase Bode plots) for the range from 10 Hz to 1 MHz. Compare your results with PSpice simulations.



# Electric Circuits II laboratory

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## Optional:

- Filter speech and noise.
- Find a microphone, add some noise with bandwidth of 20 kHz, and listen to the result with and without the filter that you built.
- Redesign a second order stage with very small capacitors (10 pF).

## Lab report:

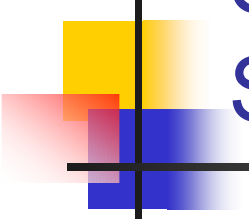
- Describe your design and the performance of your implementation. Explain differences between your expectations and the actual filter performance.



## Additional resources

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- The entire course material is available online.
- Course web pages contain links to homework assignments, laboratory exercises, and supplementary references.
- Each course lecture is audio recorded and these recordings are made available shortly after each lecture to students enrolled in the course.
- Puzzles and games



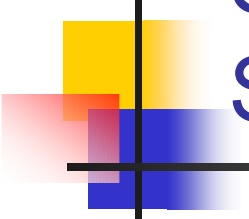
# Graduate Course: Special Topics in Theory, Analysis, and Simulation of Nonlinear Circuits

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- This is a research oriented graduate course in nonlinear circuits.
- The course aims to provide insights and understanding of complex static and dynamic behavior of circuits consisting of bipolar and MOS transistors.

## Topics:

- Global properties of electronic components, properties of nonlinear circuit equations, existence and uniqueness of dc operating points, stability of operating points and the occurrence of bistability, methods for computing solutions to dc, ac, and transient circuit equations, homotopy methods for finding such solutions and their software implementations.

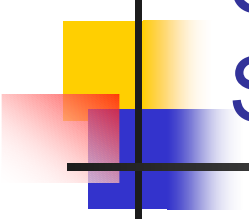


# Graduate Course: Special Topics in Theory, Analysis, and Simulation of Nonlinear Circuits

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- Emphasizes is given to the relationship of circuit theory to circuit design and its usefulness in practical applications.
- Students are introduced to various theoretical approaches and numerical methods for analyzing nonlinear electronic circuits.
- The course pre-requisites are undergraduate courses in electric circuits, electronic devices, microelectronics, and a first course in linear algebra.





# Graduate Course: Special Topics in Theory, Analysis, and Simulation of Nonlinear Circuits

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## Graduate research projects

- A final research project is an important component of the course. Software tools such as MATLAB and PSPICE are used for circuit simulations.
- **Sample projects:**
  - Stimulations of negative resistance circuits
  - Analyzing stability of nonlinear circuits
  - Computing dc operating points of nonlinear circuits
  - Analysis, modeling, and design of an IGBT-based power converter.



# Conclusions and lessons learned

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- School of Engineering Science at SFU offers a **five-year** undergraduate program in engineering.
- The program is **highly ranked** among the comprehensive Universities in Canada.
- However, many students are entering the engineering program **without** having necessary **mathematical background** and **analytical skills** to excel and enjoy the subjects taught.



# Conclusions and lessons learned

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- **Changing** undergraduate engineering curriculum to adopt **new approaches** to teaching circuits is a difficult task.
- The **curriculum** already contains a **large number of required courses**, which leaves little room for implementing desired changes such as, for example, offering separate laboratory courses as a follow-up to lecture-intensive courses in circuits.



# Conclusions and lessons learned

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- **Attracting students** to take circuits courses and motivating them to complete these courses is an essential component of teaching the course.
- **Very early** in the trimester, **simple examples** of electronic components (diodes, nonlinear resistor, op-amps, and transistors) are used **to illustrate modeling circuits** and to emphasize that linear circuits are only an approximation of electric and electronic elements.
- **Examples** employing **linear op-amps** are then used to introduce various linear analysis methods.
- **Early exposure** to **software tools** such as MATLAB and PSPICE provides a valuable complement to analysis. The analytical and simulation results are then confirmed by laboratory measurements.



# Conclusions and lessons learned

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- Feedback received from students indicates that majority of current undergraduate students find the circuits courses **difficult** and **demanding**.
- Past experiences with choosing a variety of textbooks showed that **almost any of the textbooks would prove adequate**. More important was the delivery of lectures, selection of topics covered, choice of assignments and examination questions, and quality of the laboratory equipment.
- Students overwhelmingly **enjoyed** having **laboratory** exercises and course projects, which they often complete by working in teams of two or three.
- Such laboratories, however, should be **properly maintained** and **equipped**.



## In closing and looking forward

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If we wish to generate interest in circuits among the incoming Engineering students, we need to do a better job of promoting the profession by:

- providing **bettens teaching tools** and delivery methods,
- **combining** circuit theory courses **with laboratory** exercise,
- **illustrating** the **application** of circuits in fields relevant to environment, biotechnology, and medicine
- **recognizing** and **rewarding teaching** circuits courses, and
- doing a better job in **sharing our enthusiasm** for the engineering profession.



# Acknowledgment

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Material used in this presentation emanated from a variety of undergraduate and graduate circuits courses and contributions from numerous colleagues who currently teach similar courses.



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