Spring 2007 - Tutorial 1
Analog Circuit Elements

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June 17, 2007
Outline

Discrete Circuit Elements
  The Resistor
  The Capacitor
  The Inductor

Filters
  Low-Pass Filters
  High-Pass Filters
  Bandpass Filters
  Bandreject Filters

Amplifiers
  Operational Amplifiers
    OpAmp-based Active Filters
  Transistor Amplifiers

PSpice Simulation
The Resistor

I-V characteristics: $V = IR$
The Resistor

- I-V characteristics: $V = IR$
- No frequency dependence
The Resistor

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- No frequency dependence
- Power dissipation: \( P = I^2 R \)
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- Power dissipation: $P = I^2R$
- Add in series
The Resistor

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- No frequency dependence
- Power dissipation: $P = I^2 R$
- Add in series
- Inverse total equals inverse addition in parallel
The Capacitor

I-V characteristics: \( I = C \frac{dV}{dt} \)
The Capacitor

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- Frequency dependent impedance: $Z = \frac{1}{j\omega C}$
The Capacitor

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- Add in parallel
The Capacitor

- I-V characteristics: \( I = C \frac{dV}{dt} \)
- Frequency dependent impedance: \( Z = \frac{1}{j \omega C} \)
- No power dissipation (ideally)
- Add in parallel
- Inverse total equals inverse addition in series

\[ \frac{C_1 C_2}{C_1 + C_2} \]
The Inductor

I-V characteristics: \( V = L \frac{di}{dt} \)
The Inductor

- **I-V characteristics**: \( V = L \frac{di}{dt} \)
- **Frequency dependent impedance**: \( Z = j\omega L \)
The Inductor

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The Inductor

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- Frequency dependent impedance: $Z = j\omega L$
- No power dissipation (ideally)
- Add in series
The Inductor

- **I-V characteristics:** \( V = L \frac{di}{dt} \)
- **Frequency dependent impedance:** \( Z = j\omega L \)
- **No power dissipation (ideally)**
- **Add in series**
- **Inverse total equals inverse addition in parallel**
Overview

- Take advantage of frequency-dependence of components
Overview

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- Filter out certain frequencies
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- Each one characterized by a transfer function
Overview

- Take advantage of frequency-dependence of components
- Filter out certain frequencies
- Each one characterized by a transfer function
- Many types (high-pass, low-pass, bandpass, band-reject)
RC Low Pass Filter

- Uses a resistor and capacitor

![RC Low Pass Filter Diagram]

\[ i(t) \]

\[ V_{in} \]

\[ V_{out} \]
RC Low Pass Filter

- Uses a resistor and capacitor
- Transfer function:

\[ V_{out} = \frac{1}{s + \frac{1}{RC}} V_{in} \]
RC Low Pass Filter

- Uses a resistor and capacitor
- Transfer function:
  \[ V_{out} = \frac{1}{s + \frac{1}{RC}} \cdot V_{in} \]
- Bandwidth: 0 to \( \omega_c = \frac{1}{RC} \)
RL Low Pass Filter

- Uses a resistor and inductor

\[ V_{in} \rightarrow i(t) \rightarrow V_{out} \]
RL Low Pass Filter

- Uses a resistor and inductor
- Transfer function:

\[ V_{out} = \frac{R}{s + \frac{R}{L}} V_{in} \]
**RL Low Pass Filter**

- Uses a resistor and inductor
- Transfer function:
  \[ V_{out} = \frac{R}{L} \frac{V_{in}}{s + \frac{R}{L}} \]
- Bandwidth: 0 to \( \omega_c = \frac{R}{L} \)
RC High Pass Filter

- Uses a resistor and capacitor

![RC High Pass Filter Diagram](diagram.png)
RC High Pass Filter

- Uses a resistor and capacitor
- Transfer function:
  \[ V_{out} = \frac{s}{s + \frac{1}{RC}} V_{in} \]
RC High Pass Filter

- Uses a resistor and capacitor
- Transfer function:
  \[ V_{\text{out}} = \frac{s}{s + \frac{1}{RC}} V_{\text{in}} \]
- Bandwidth: \( \omega_c = \frac{1}{RC} \) to \( \infty \)
RL High Pass Filter

- Uses a resistor and inductor

\[ V_{\text{in}} \rightarrow V_{\text{out}} \]
RL High Pass Filter

- Uses a resistor and inductor
- Transfer function:
  \[ V_{out} = \frac{s}{s + \frac{R}{L}} V_{in} \]
RL High Pass Filter

- Uses a resistor and inductor
- Transfer function:
  \[ V_{out} = \frac{s}{s + \frac{R}{L}} V_{in} \]
- Bandwidth: \( \omega_c = \frac{R}{L} \) to \( \infty \)
Series RLC Bandpass Filter

- Uses a resistor, inductor and capacitor

\[ I_{\text{out}} \]
\[ V_{\text{in}} \]
Series RLC Bandpass Filter

- Uses a resistor, inductor and capacitor
- Transfer function:

\[ I_{out} = \frac{sC}{s^2 + s\frac{R}{L} + \frac{1}{LC}} V_{in} \]
Series RLC Bandpass Filter

- Uses a resistor, inductor and capacitor
- Transfer function:
  \[ I_{\text{out}} = \frac{sC}{s^2 + s\frac{R}{L} + \frac{1}{LC}} V_{\text{in}} \]
- Bandwidth:
  \[ \omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \]
  to
  \[ \omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \]
Parallel RLC Bandpass Filter

- Uses a resistor, inductor and capacitor
Parallel RLC Bandpass Filter

- Uses a resistor, inductor and capacitor
- Transfer function:

\[ V_{out} = \frac{s \frac{1}{C} \cdot \frac{1}{RC}}{s^2 + s \frac{1}{RC} + \frac{1}{LC}} I_{in} \]
Parallel RLC Bandpass Filter

- Uses a resistor, inductor and capacitor
- Transfer function:
  \[ V_{out} = \frac{s \frac{1}{C}}{s^2 + s \frac{1}{RC} + \frac{1}{LC}} I_{in} \]
- Bandwidth:
  \[ \omega_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} \]
  to \[ \omega_2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} \]
RLC Bandreject Filter

- Uses a resistor, inductor and capacitor
RLC Bandreject Filter

- Uses a resistor, inductor and capacitor
- Transfer function:

\[ V_{out} = \frac{s^2 + \frac{1}{LC}}{s^2 + s\frac{R}{L} + \frac{1}{LC}} \cdot V_{in} \]
RLC Bandreject Filter

- Uses a resistor, inductor and capacitor
- Transfer function:
\[ V_{out} = \frac{s^2 + \frac{1}{LC}}{s^2 + s \frac{R}{L} + \frac{1}{LC}} V_{in} \]
- Rejection:
\[ \omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \]
\[ \omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \]
Overview

- Increase the magnitude of a certain input signal
Overview

- Increase the magnitude of a certain input signal
- Very dependent on frequency
Overview

- Increase the magnitude of a certain input signal
- Very dependent on frequency
- Several types, most popular is the operational amplifier (OpAmp)
Now implemented on ICs, cheap
Overview

- Now implemented on ICs, cheap
- Most widely used amplifier in electronics
Overview

- Now implemented on ICs, cheap
- Most widely used amplifier in electronics
- Differential inputs with high gain
Overview

- Now implemented on ICs, cheap
- Most widely used amplifier in electronics
- Differential inputs with high gain
- Gain usually maintained at constant value using negative feedback
Negative Feedback Configuration

- Amplifier Gain (ideal):
  \[ A_v = \frac{V_o}{V_i} = -\frac{R_2}{R_1} \]
Negative Feedback Configuration

- **Amplifier Gain (ideal):**
  \[ A_v = \frac{V_o}{V_i} = -\frac{R_2}{R_1} \]

- **Amplifier Gain:**
  \[ A_v = \frac{V_o}{V_i} = \frac{-R_2/R_1}{1 + \frac{s}{\omega_t/(1+R_2/R_1)}} \]
Negative Feedback Configuration

- Amplifier Gain (ideal):
  \[ A_v = \frac{V_o}{V_i} = -\frac{R_2}{R_1} \]

- Amplifier Gain:
  \[ A_v = \frac{V_o}{V_i} = \frac{-R_2/R_1}{1 + \frac{s}{\omega_t/(1+R_2/R_1)}} \]

- Usually has good frequency response
Low Pass Filter

![Low Pass Filter Circuit Diagram](image)
High Pass Filter
Bandpass Filter

- Simplest: Combine high-pass and low-pass filter in series
Bandpass Filter

- Simplest: Combine high-pass and low-pass filter in series
- Can also be done with single OpAmp
Transistor Amplifiers

- Used in integrated circuits
Transistor Amplifiers

- Used in integrated circuits
- Will be our project’s primary component
Transistor Amplifiers

- Used in integrated circuits
- Will be our project’s primary component
- Will be the subject of Tutorial 2
Overview

- Very useful circuit simulation package
Overview

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- Can simulate the characteristics of any circuit
Overview

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- Can simulate the characteristics of any circuit
- Useful for ECE 100 labs, used in ECE 241 & 332
Overview

- Very useful circuit simulation package
- Can simulate the characteristics of any circuit
- Useful for ECE 100 labs, used in ECE 241 & 332
- We will be using it to simulate the circuits discussed
PSpice Syntax

- First line is always the title line
PSpice Syntax

- First line is always the title line
- Syntax: NAME NODE_A NODE_B VALUE
PSpice Syntax

- First line is always the title line
- Syntax: NAME NODE_A NODE_B VALUE
- Specify components according to their name
PSpice Syntax

- First line is always the title line
- Syntax: NAME NODE_A NODE_B VALUE
- Specify components according to their name
  - Resistor: Rxx
PSpice Syntax

- First line is always the title line
- Syntax: NAME NODE_A NODE_B VALUE
- Specify components according to their name
  - Resistor: Rxx
  - Capacitor: Cxx
PSpice Syntax

- First line is always the title line
- Syntax: NAME NODE_A NODE_B VALUE
- Specify components according to their name
  - Resistor: Rxx
  - Capacitor: Cxx
  - Inductor: Cxx
Sample Code - RC Low-Pass Filter

v.in 1 0 ac 1 pulse( -1 1 0 0 0 1m 2m )
r1 1 2 10k
c1 2 0 10n
* analysis commands
.ac dec 20 10 1meg
.tran 700n 700u
.probe
.end