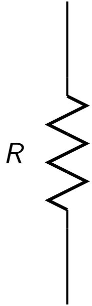
Spring 2007 - Tutorial 1
Analog Circuit Elements

UW ASIC Design Team

June 17, 2007

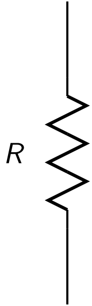
Outline

The Resistor



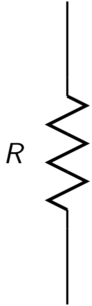
- I-V characteristics: $V = IR$

The Resistor



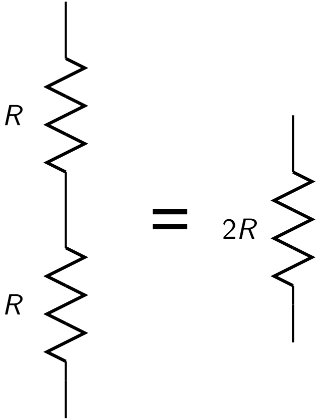
- I-V characteristics: $V = IR$
- No frequency dependence

The Resistor



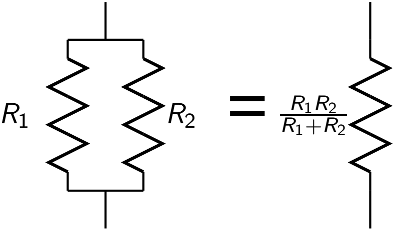
- I-V characteristics: $V = IR$
- No frequency dependence
- Power dissipation: $P = I^2R$

The Resistor



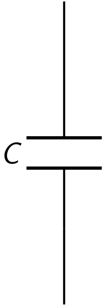
- I-V characteristics: $V = IR$
- No frequency dependence
- Power dissipation: $P = I^2R$
- Add in series

The Resistor



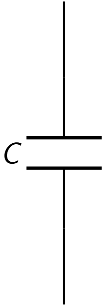
- I-V characteristics: $V = IR$
- No frequency dependence
- Power dissipation: $P = I^2R$
- Add in series
- Inverse total equals inverse addition in parallel

The Capacitor



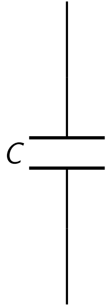
- I-V characteristics: $I = C\frac{dV}{dt}$

The Capacitor



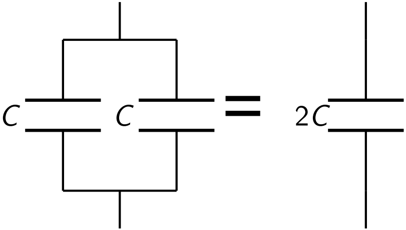
- I-V characteristics: $I = C\frac{dV}{dt}$
- Frequency dependent impedance: $Z = \frac{1}{j\omega C}$

The Capacitor



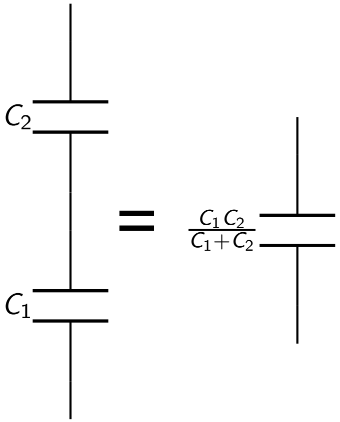
- I-V characteristics: $I = C\frac{dV}{dt}$
- Frequency dependent impedance: $Z = \frac{1}{j\omega C}$
- No power dissipation (ideally)

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

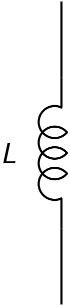
The Capacitor



- 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

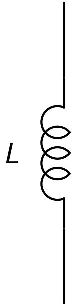
UW ASIC design team

The Inductor



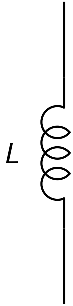
- I-V characteristics: $V = L\frac{di}{dt}$

The Inductor



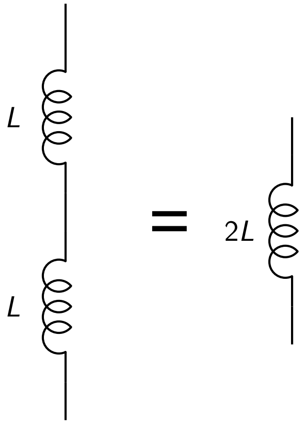
- I-V characteristics: $V = L\frac{di}{dt}$
- Frequency dependent impedance: $Z = j\omega L$

The Inductor



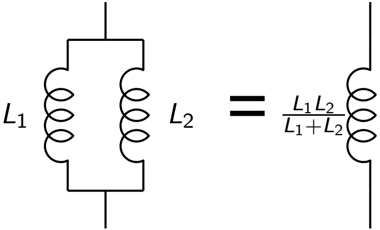
- I-V characteristics: $V = L\frac{di}{dt}$
- Frequency dependent impedance: $Z = j\omega L$
- No power dissipation (ideally)

The Inductor



- I-V characteristics: $V = L\frac{di}{dt}$
- 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

- Take advantage of frequency-dependence of components
- Filter out certain frequencies

Overview

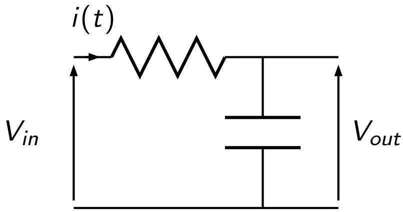
- Take advantage of frequency-dependence of components
- Filter out certain frequencies
- Each one characterized by a transfer function

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

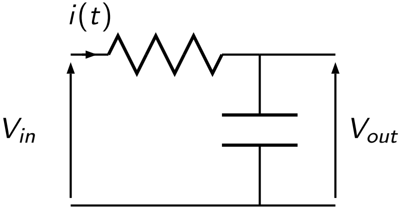
- Uses a resistor and capacitor



RC Low Pass Filter

- Uses a resistor and capacitor
- Transfer function:

$$V_{out} = \frac{\frac{1}{RC}}{s + \frac{1}{RC}} V_{in}$$

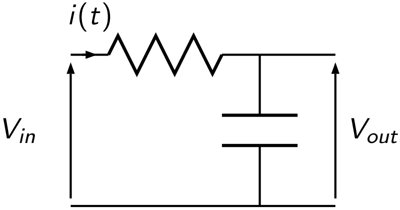


RC Low Pass Filter

- Uses a resistor and capacitor
- Transfer function:

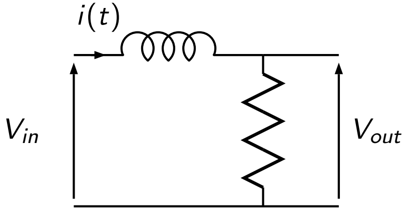
$$V_{out} = \frac{\frac{1}{RC}}{s + \frac{1}{RC}} V_{in}$$

- Bandwidth: 0 to $\omega_c = \frac{1}{RC}$



RL Low Pass Filter

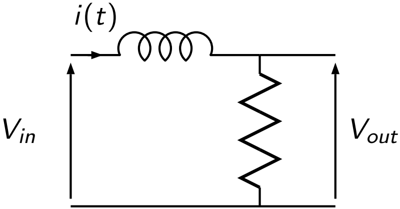
- Uses a resistor and inductor



RL Low Pass Filter

- Uses a resistor and inductor
- Transfer function:

$$V_{out} = \frac{\frac{R}{L}}{s + \frac{R}{L}} V_{in}$$

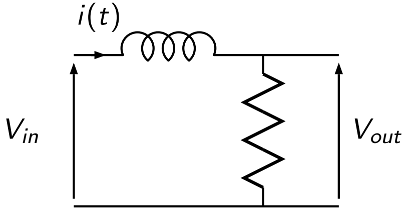


RL Low Pass Filter

- Uses a resistor and inductor
- Transfer function:

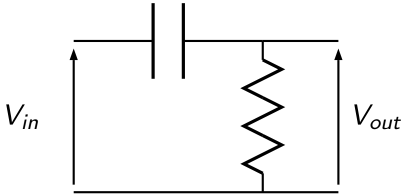
$$V_{out} = \frac{\frac{R}{L}}{s + \frac{R}{L}} V_{in}$$

- Bandwidth: 0 to $\omega_c = \dfrac{R}{L}$



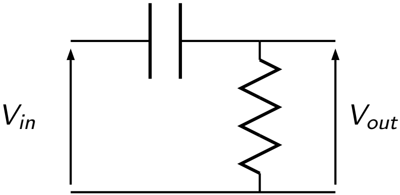
RC High Pass Filter

- Uses a resistor and capacitor



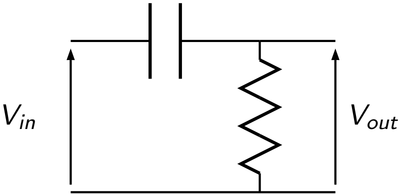
RC High Pass Filter

- Uses a resistor and capacitor
- Transfer function:
$$V_{out} = \frac{s}{s + \frac{1}{RC}} V_{in}$$



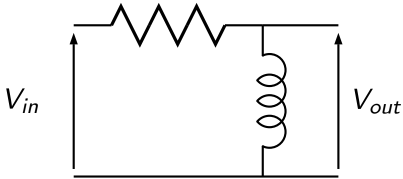
RC High Pass Filter

- Uses a resistor and capacitor
- Transfer function:
  $$V_{out} = \frac{s}{s + \frac{1}{RC}} V_{in}$$
- Bandwidth: $\omega_c = \dfrac{1}{RC}$ to ∞



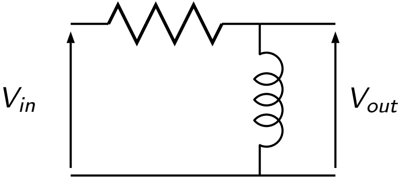
RL High Pass Filter

- Uses a resistor and inductor



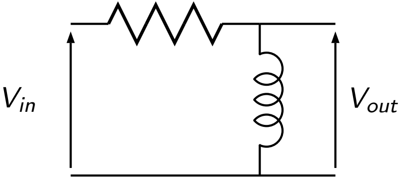
RL High Pass Filter

- Uses a resistor and inductor
- Transfer function:
  $$V_{out} = \frac{s}{s + \frac{R}{L}} V_{in}$$



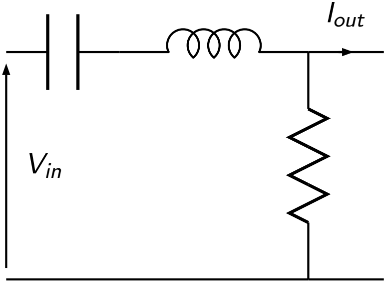
RL High Pass Filter

- Uses a resistor and inductor
- Transfer function:
$$V_{out} = \frac{s}{s + \frac{R}{L}} V_{in}$$
- Bandwidth: $\omega_c = \frac{R}{L}$ to ∞



Series RLC Bandpass Filter

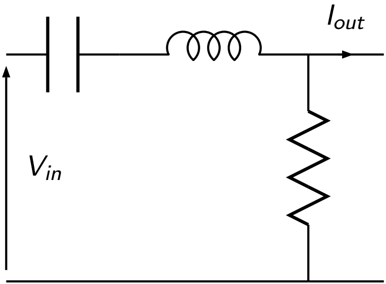
- Uses a resistor, inductor and capacitor



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

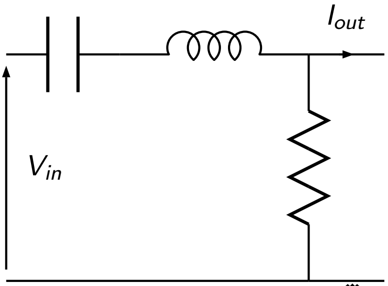
- Uses a resistor, inductor and capacitor
- Transfer function:

$$I_{out} = \frac{sC}{s^2 + s\frac{R}{L} + \frac{1}{LC}} V_{in}$$

- Bandwidth:

$$\omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \text{ to}$$

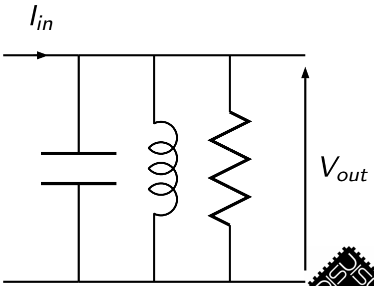
$$\omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$



UW ASIC
design team

Parallel RLC Bandpass Filter

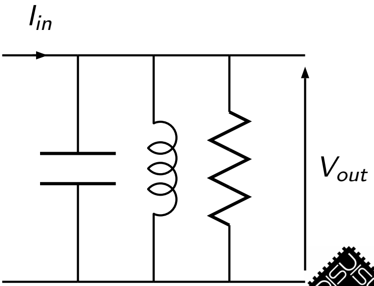
- Uses a resistor, inductor and capacitor



Parallel RLC Bandpass Filter

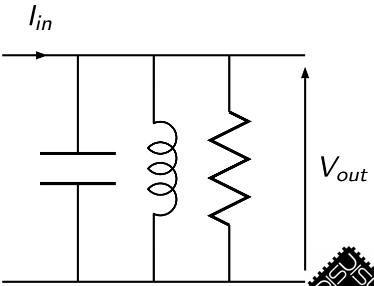
- Uses a resistor, inductor and capacitor
- Transfer function:

$$V_{out} = \frac{s\frac{1}{C}}{s^2 + s\frac{1}{RC} + \frac{1}{LC}} I_{in}$$



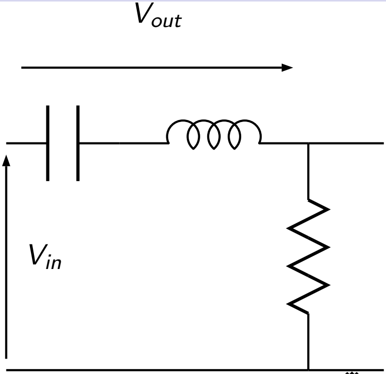
Parallel RLC Bandpass Filter

- 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:
$$\omega_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$
$$\text{to } \omega_2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$



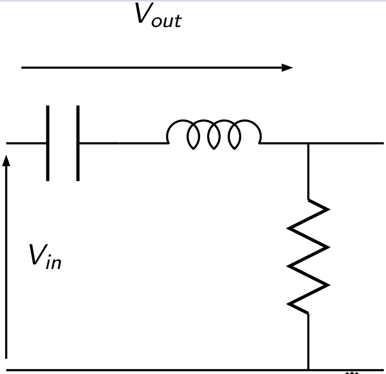
RLC Bandreject Filter

- Uses a resistor, inductor and capacitor



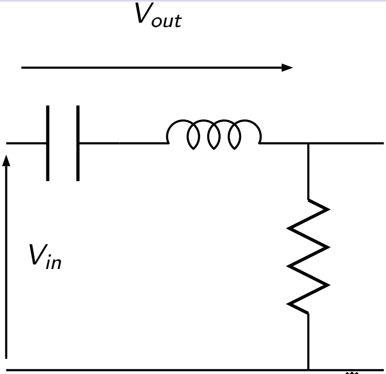
RLC Bandreject Filter

- Uses a resistor, inductor and capacitor
- Transfer function:
  $$V_{out} = \frac{s^2 + \frac{1}{LC}}{s^2 + s\frac{R}{L} + \frac{1}{LC}} V_{in}$$



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:
$$\omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \text{ to}$$
$$\omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$



Overview

- Increase the magnitude of a certain input signal

Overview

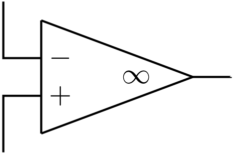
- Increase the magnitude of a certain input signal
- Very dependent on frequency

Overview

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

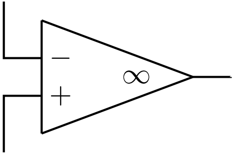
Overview

- Now implemented on ICs, cheap



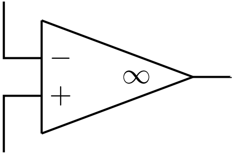
Overview

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



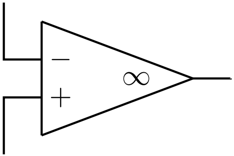
Overview

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



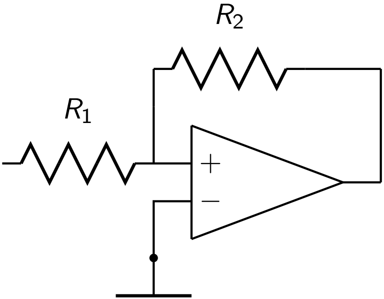
Overview

- 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



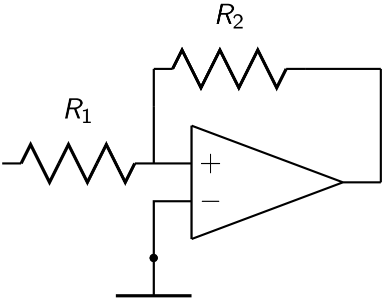
Negative Feedback Configuration

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



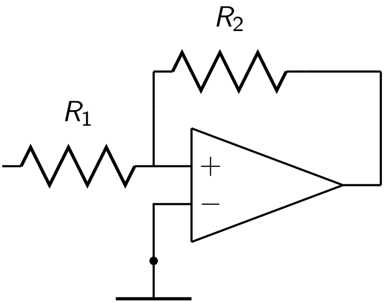
Negative Feedback Configuration

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

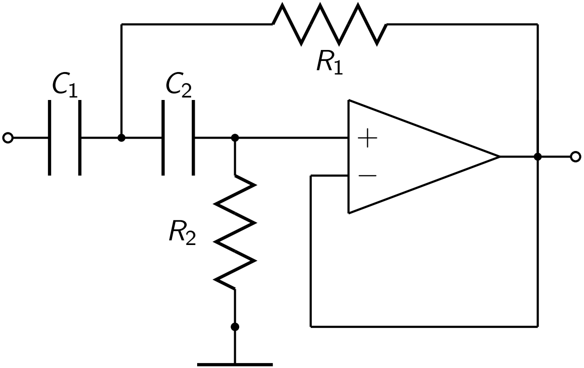


Negative Feedback Configuration

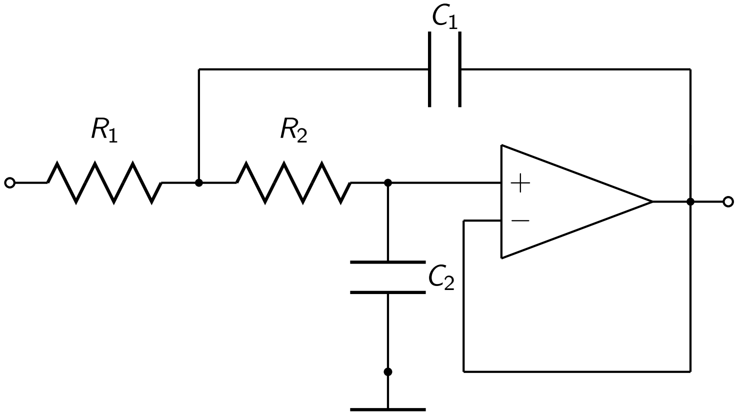
- Amplifier Gain (ideal):
  $$A_v = \frac{V_o}{V_i} = -\frac{R_2}{R_1}$$
- Amplifier Gain:
  $$A_v = \frac{V_o}{V_i} = \frac{-R_2/R_1}{1 + \frac{s}{\omega_t/(1+R_2/R_1)}}$$
- Usually has good frequency response



Low Pass Filter



High Pass Filter



Bandpass Filter

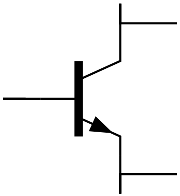
- Simplest: Combine high-pass and low-pass filter in series

Bandpass Filter

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

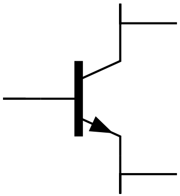
Transistor Amplifiers

- Used in integrated circuits



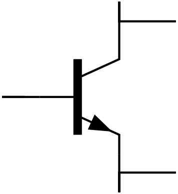
Transistor Amplifiers

- 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

- Very useful circuit simulation package
- Can simulate the characteristics of any circuit

Overview

- Very useful circuit simulation package
- 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
```