

Spring 2007 - Tutorial 1

Analog Circuit Elements



UW ASIC
design ♦ team

UW ASIC Design Team

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

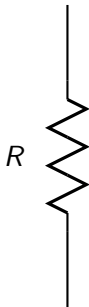
OpAmp-based Active Filters

Transistor Amplifiers

PSpice Simulation



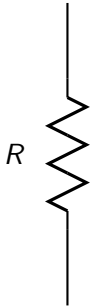
The Resistor



- ▶ I-V characteristics: $V = IR$



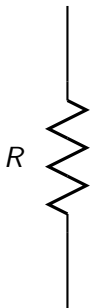
The Resistor



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

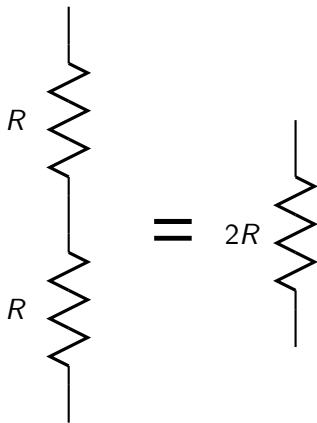


The Resistor



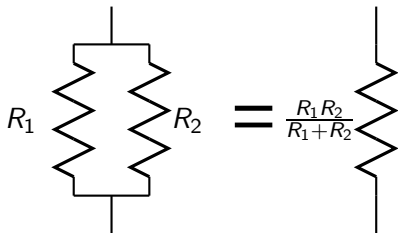
- ▶ I-V characteristics: $V = IR$
- ▶ No frequency dependence
- ▶ Power dissipation: $P = I^2R$

The Resistor



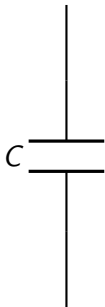
- ▶ I-V characteristics: $V = IR$
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- ▶ Add in series

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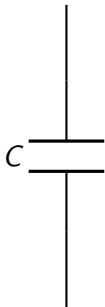
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- ▶ Add in series
- ▶ Inverse total equals inverse addition in parallel

The Capacitor



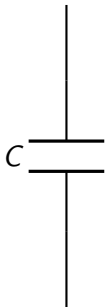
- ▶ I-V characteristics: $I = C \frac{dV}{dt}$

The Capacitor



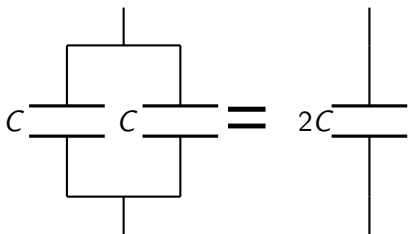
- ▶ I-V characteristics: $I = C \frac{dV}{dt}$
- ▶ Frequency dependent impedance:
 $Z = \frac{1}{j\omega C}$

The Capacitor



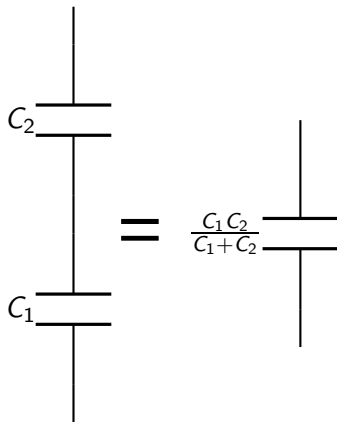
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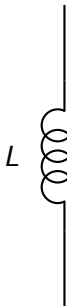
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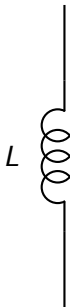
- ▶ I-V characteristics: $I = C \frac{dV}{dt}$
- ▶ Frequency dependent impedance: $Z = \frac{1}{j\omega C}$
- ▶ No power dissipation (ideally)
- ▶ Add in parallel
- ▶ Inverse total equals inverse addition in series

The Inductor



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

The Inductor



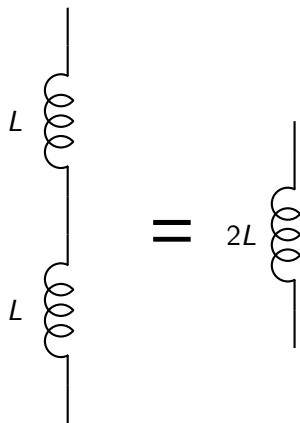
- ▶ I-V characteristics: $V = L \frac{di}{dt}$
- ▶ Frequency dependent impedance:
 $Z = j\omega L$

The Inductor



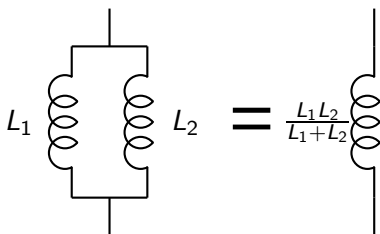
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Overview

- ▶ 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



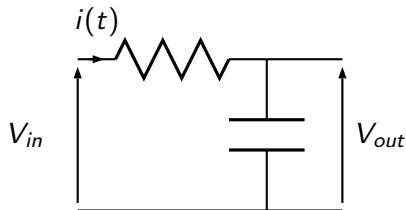
Overview

- ▶ 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

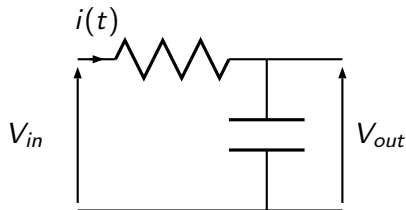
- ▶ Uses a resistor and capacitor



RC Low Pass Filter

- ▶ Uses a resistor and capacitor
- ▶ Transfer function:

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



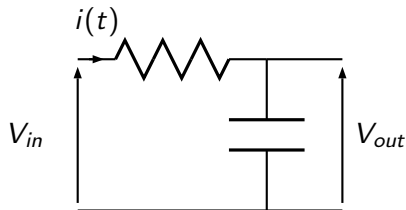
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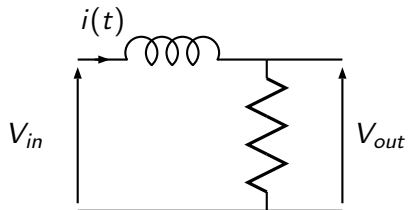
$$V_{out} = \frac{\frac{1}{RC}}{s + \frac{1}{RC}} V_{in}$$

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



RL Low Pass Filter

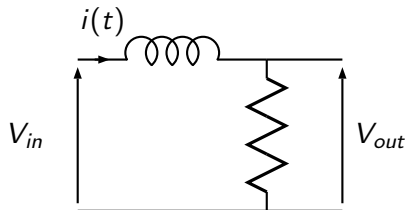
- ▶ Uses a resistor and inductor



RL Low Pass Filter

- ▶ Uses a resistor and inductor
- ▶ Transfer function:

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



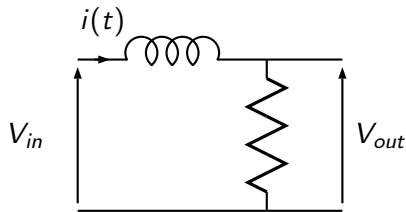
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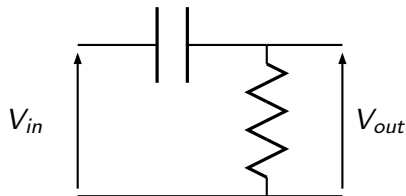
$$V_{out} = \frac{\frac{R}{L}}{s + \frac{R}{L}} V_{in}$$

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



RC High Pass Filter

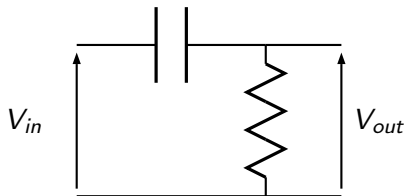
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RC High Pass Filter

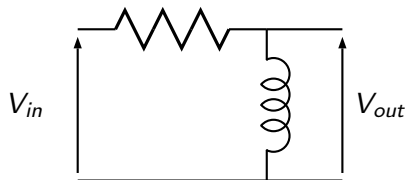
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RL High Pass Filter

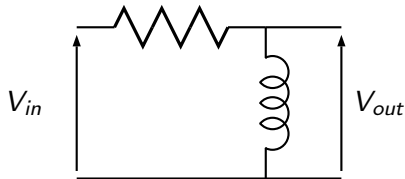
- ▶ Uses a resistor and inductor



RL High Pass Filter

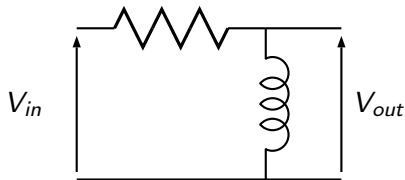
- ▶ Uses a resistor and inductor
- ▶ Transfer function:

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



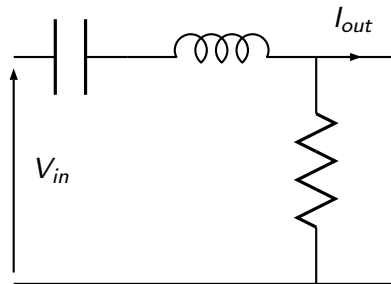
RL High Pass Filter

- ▶ 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

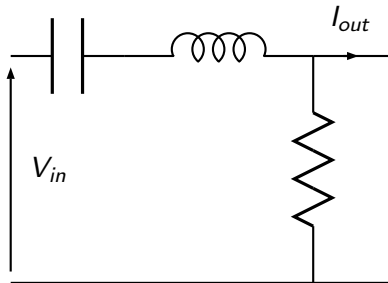
- ▶ Uses a resistor, inductor and capacitor



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

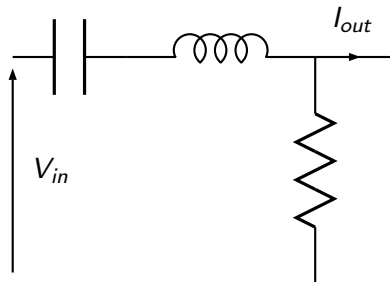
- ▶ Transfer function:

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

- ▶ Bandwidth:

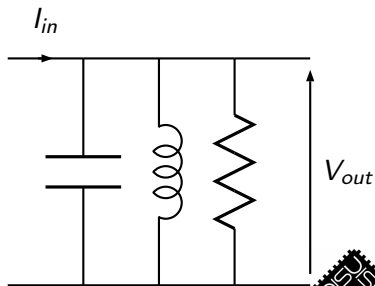
$$\omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \text{ to}$$

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



Parallel RLC Bandpass Filter

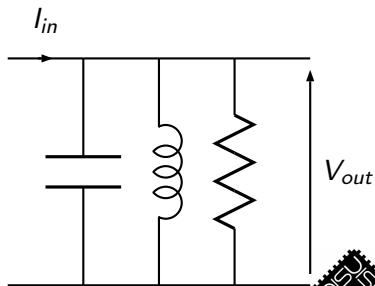
- ▶ Uses a resistor, inductor and capacitor



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

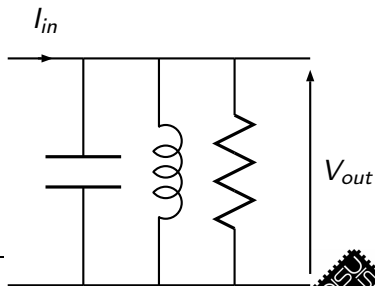
- ▶ Transfer function:

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

- ▶ Bandwidth:

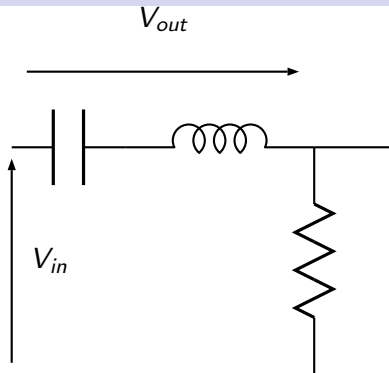
$$\omega_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$

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



RLC Bandreject Filter

- ▶ Uses a resistor, inductor and capacitor

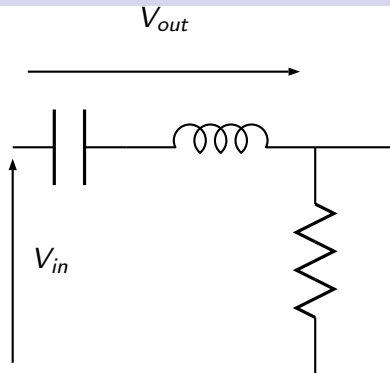


RLC Bandreject Filter

- ▶ 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

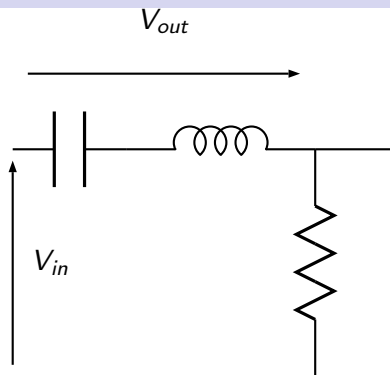
- ▶ Transfer function:

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

- ▶ 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



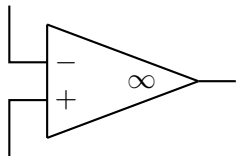
Overview

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



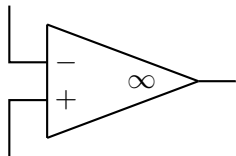
Overview

- ▶ Now implemented on ICs, cheap



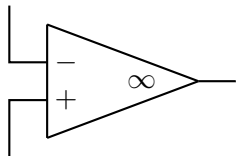
Overview

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



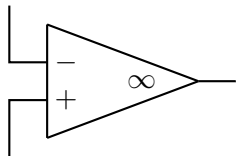
Overview

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



Overview

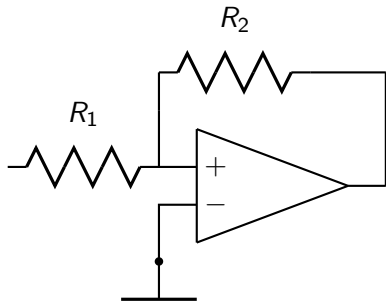
- ▶ Now implemented on ICs, cheap
- ▶ Most widely used amplifier in electronics
- ▶ Differential inputs with high gain
- ▶ Gain usually maintained at constant value using negative feedback



Negative Feedback Configuration

- ▶ Amplifier Gain (ideal):

$$A_v = \frac{V_o}{V_i} = -\frac{R_2}{R_1}$$



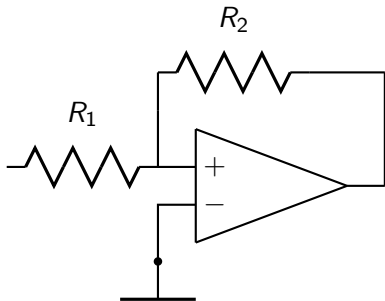
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- ▶ Amplifier Gain:

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



Negative Feedback Configuration

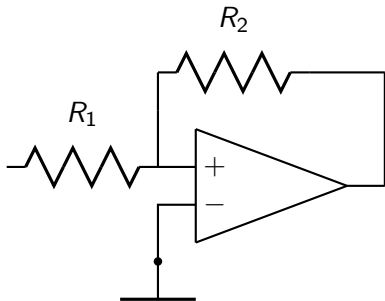
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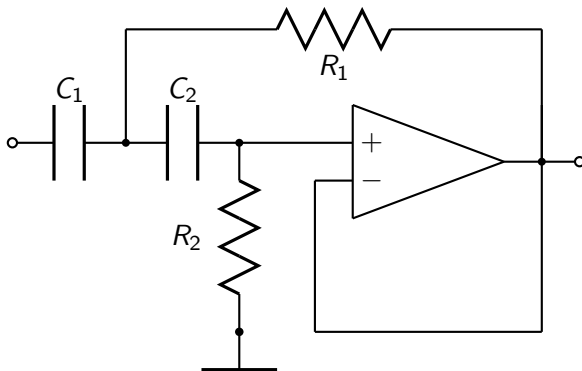
- ▶ Amplifier Gain:

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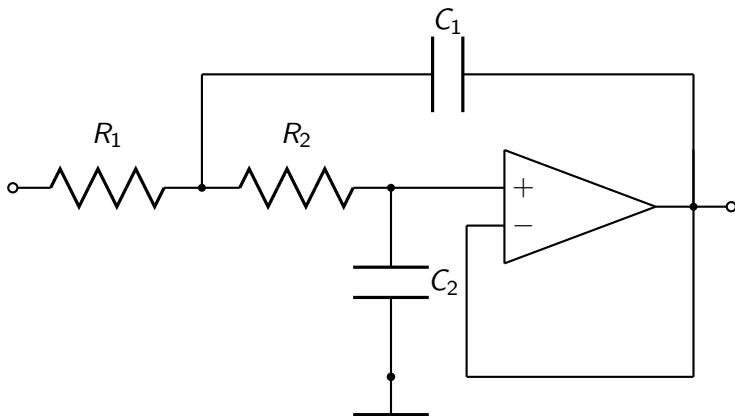
- ▶ Usually has good frequency response



Low Pass Filter



High Pass Filter



Bandpass Filter

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



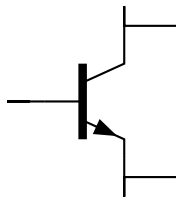
Bandpass Filter

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



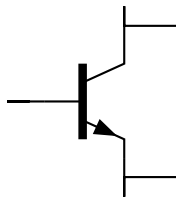
Transistor Amplifiers

- ▶ Used in integrated circuits



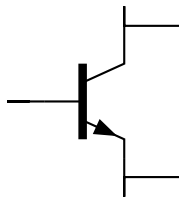
Transistor Amplifiers

- ▶ 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



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- ▶ Can simulate the characteristics of any circuit



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- ▶ 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

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- ▶ Syntax: NAME NODE_A NODE_B VALUE



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 - ▶ Resistor: Rxx



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 - ▶ 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: Lxx



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
```

