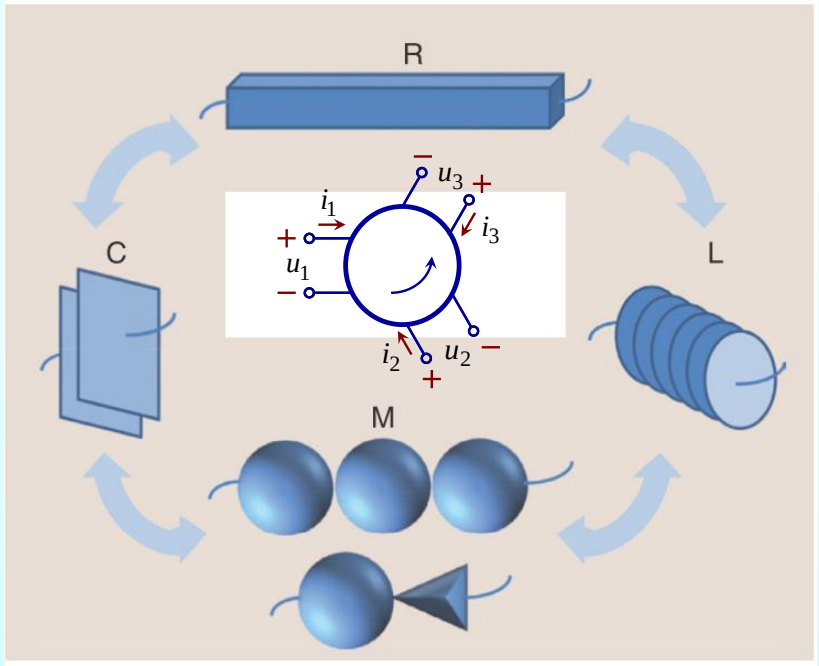
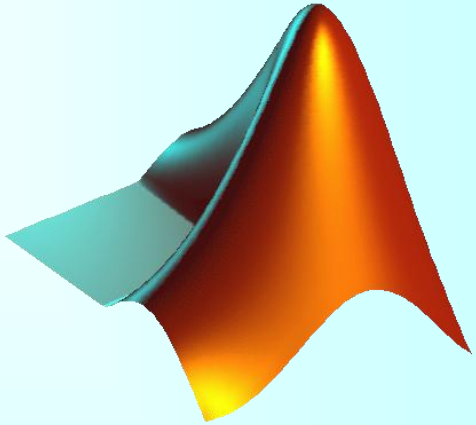
# Практикум из рачунарске анализе трофазних кола

# 1. Увод



Милка Потребић Иваниш

Никола Баста

# Практикум из рачунарске анализе трофазних кола 19E072ПРТК

- **Настава се изводи према текућем студијском програму који је Електротехнички факултет акредитовао** http://www.etf.bg.ac.rs
- Студијски програм: **Електротехника и рачунарство**
- Изборно подручје (модул): **Енергетика**
- **Циљ.** Излагање основних концепата анализе помоћу рачунара који се користе у софтверским пакетима за симулацију трофазних електричних кола са гледишта инжењера и истраживача електроенергетике. Увођење основа за анализу модела електроенергетских система и направа за нумеричку и симболичку анализу у временском и фреквенцијском домену. Изградња основних знања из теорије и примене симетричних компоненти.
- **Исход.** Разумевање основних концепата анализе трофазних електричних кола помоћу рачунара и одговарајућих математичких алгоритама. Решавање линеарних трофазних електричних кола у временском и фреквенцијском домену помоћу система компјутерске алгебре.
- **Садржај.** Основни концепти рачунарске симулације трофазних електричних кола. Симболичко и нумеричко израчунавање симетричних компоненти. Моделовање и симулација електроенергетских водова, компоненти и система помоћу савремених софтверских алата.
- **Наставници:** Др **Милка Потребић Иваниш**, редовни професор, соба 64 (milka_potrebic@etf.rs);
  Др **Никола Баста**, доцент, соба 63 (nbasta@etf.rs).
- **Асистент: Ања Ковачевић**, мс. инж.
- Белешке са предавања и лаб. вежби, примери испитних задатака и питања, **http://tek.etf.rs**
- **Додатни материјали и консултације биће организовани преко канала на MS Teams платформи** (линкови за канале су на адреси **http://tek.etf.rs**)
- **Начин одржавања наставе.** Рачунски центар.
- **Начин полагања испита.** 1) Решавање задатака на рачунару у пару (или самостално) у РЦ, или алтернативно
  2) издрада два домаћа задатка у пару (или самостално) са пратећим извештајем у виду презентецајује која се усмено брани.
  Испит се може полагати у сваком испитном року.
  Усмена одбрана домаћих задатака се заказује са предметним наставницима.
  **За израду домаћих задатака јавити се е-поштом Милки Потребић Иваниш.**
- **Пратити** званично представљање предмета и објављивање општих службених порука на адреси **http://tek.etf. rs/**

# Рачунарски (софтверски) алати

- *Mathematica*, WolframAlpha, MuPAD, **Maxima**, **SymPy**, **SymPy Live**, **SymPy Gamma**
- MATLAB, **Scilab**, **Octave**, **FreeMat**, **Julia**
- LTspice, **QucsStudio**, **ngspice**, **Xyce**, **XCircuit**
- **Python**, MathCAD, MAPLE, GeoGebra, Sage
- Symbolab, SpeQ Mathematics, meta-calculator, Desmos, …
- Android apk: NCalc+, CalcES, SymJa CAS, Scientific Calculator Pro, CYZSoft Scientific Calculator Plus

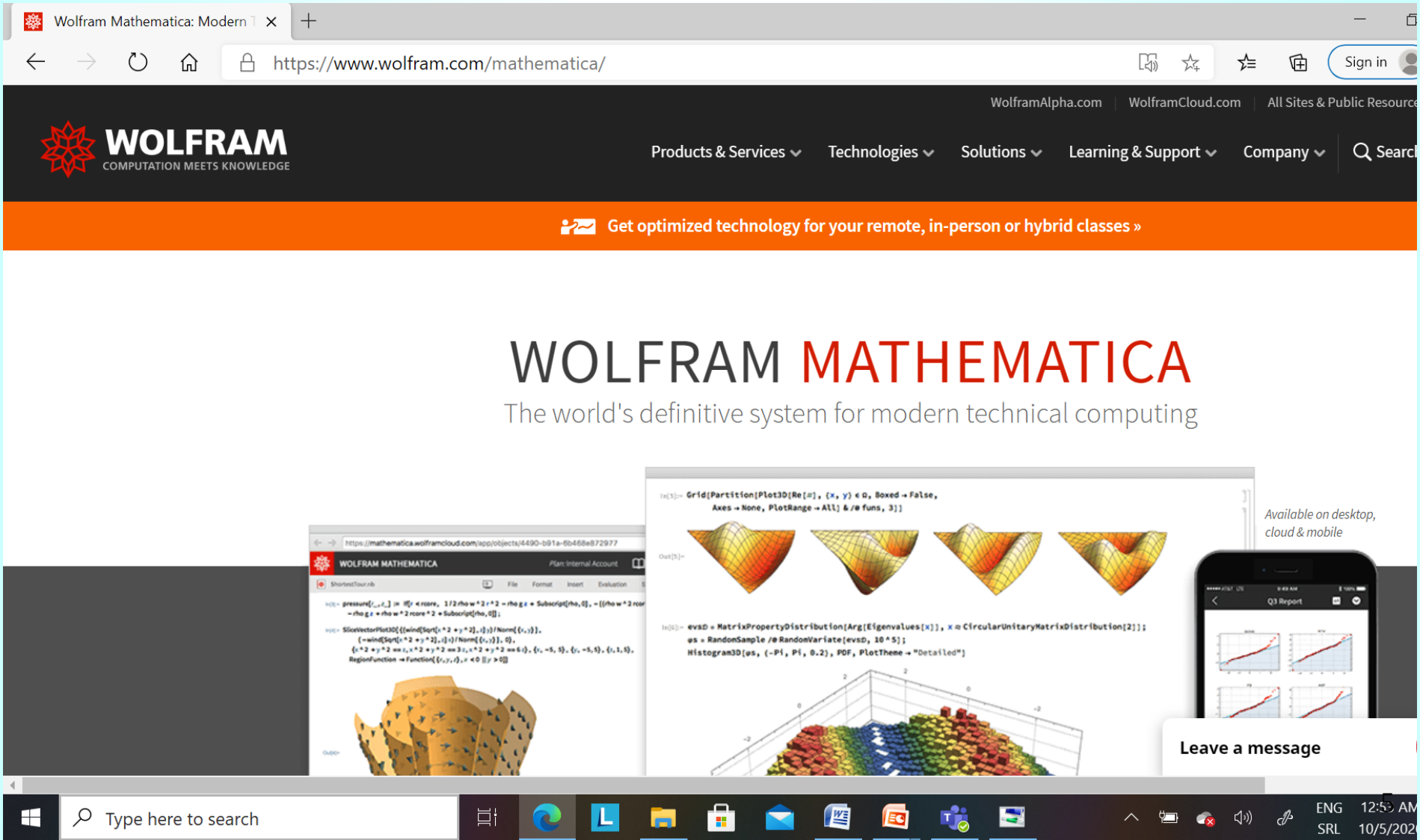
**Free/Libre Open Source Software (FLOSS)**

# Моделовање електричних кола

- PSpice, ngSpice, Xcos, SciLab, TINA-TI, Micro-Cap, Plexim, 5Spice…
- **Online Circuit Simulator**: DoCircuits, Circuit Lab, PartSim, EasyEda, Multisim, PartQuest (SystemVision Cloud)...
- **Android circuit simulator:**
  Electric Circuit Studio,
  Circuit Safari SPICE Simulator...

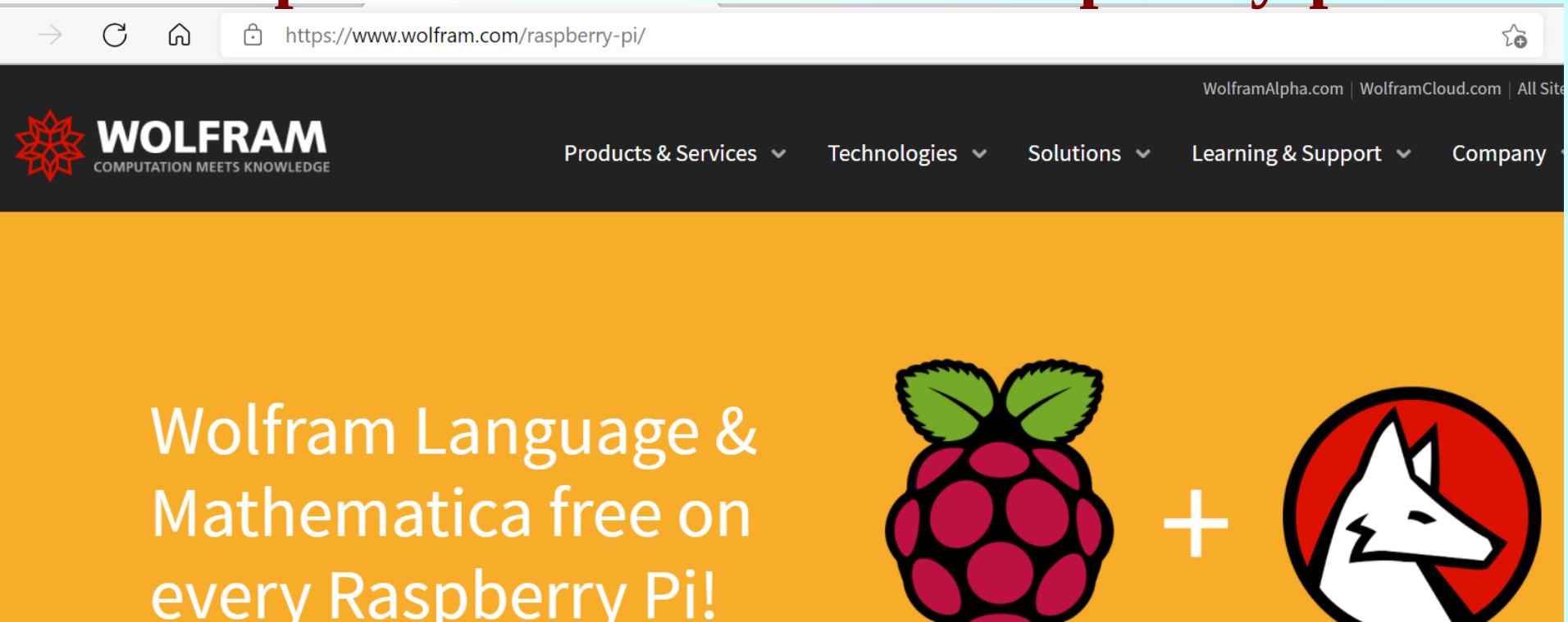
# Mathematica

## https://www.wolfram.com/mathematica/



# Mathematica free on every Raspberry Pi!

## https://www.wolfram.com/raspberry-pi/



www.wolframalpha.com

Give your brain a quick workout with Wolfram Problem Generator.

WolframAlpha computational... knowledge engine

y' +1000 * y = 10000, y(0)=-10

Examples Random

Input:

$\{y'(x) + 1000\, y(x) = 10\,000,\ y(0) = -10\}$

ODE classification:

first-order linear ordinary differential equation

Alternate forms:

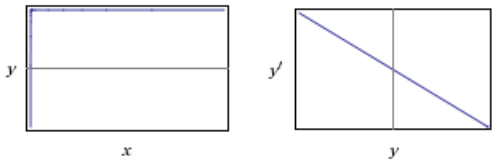
$\{y'(x) = 10\,000 - 1000\, y(x),\ y(0) = -10\}$

$\{y'(x) + 1000\,(y(x) - 10) = 0,\ y(0) = -10\}$

Differential equation solution: Approximate form | Step-by-step solution

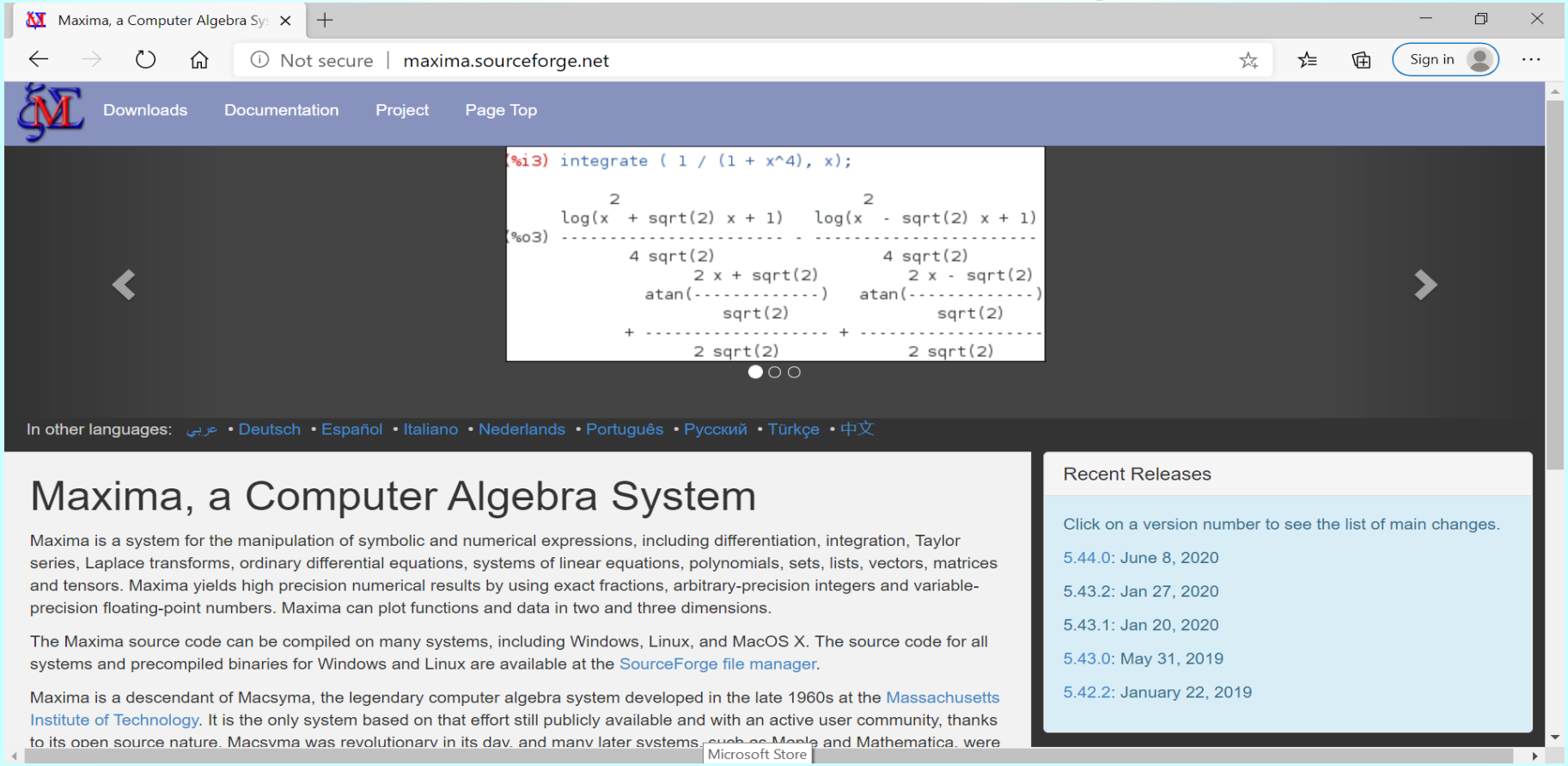
$y(x) = 10 - 20\, e^{-1000\, x}$

Plots of the solution:



# Maxima

## http://maxima.sourceforge.net/



# Maxima on line

## http://maxima.cesga.es/

Servicio proporcionado por CESGA

*Maxima on line*

Help: Español, English Galego

```
expand((x-2)^3*(x+1/3)^2);

solve(x^2-x+2=0);

invert(matrix([2,3,1], [a,0,0], [1,4,8]));

integrate(x * sin(x), x);

draw3d(explicit(x^2+y^2,x,-1,1,y,-1,1));
```

Clic Clear

AVISO LEGAL

(%i1) expand((x-2)^3*(x+1/3)^2);

(%o1) $x^5-\frac{16\,x^4}{3}+\frac{73\,x^3}{9}-\frac{2\,x^2}{3}-4\,x-\frac{8}{9}$

(%i2) solve(x^2-x+2=0);

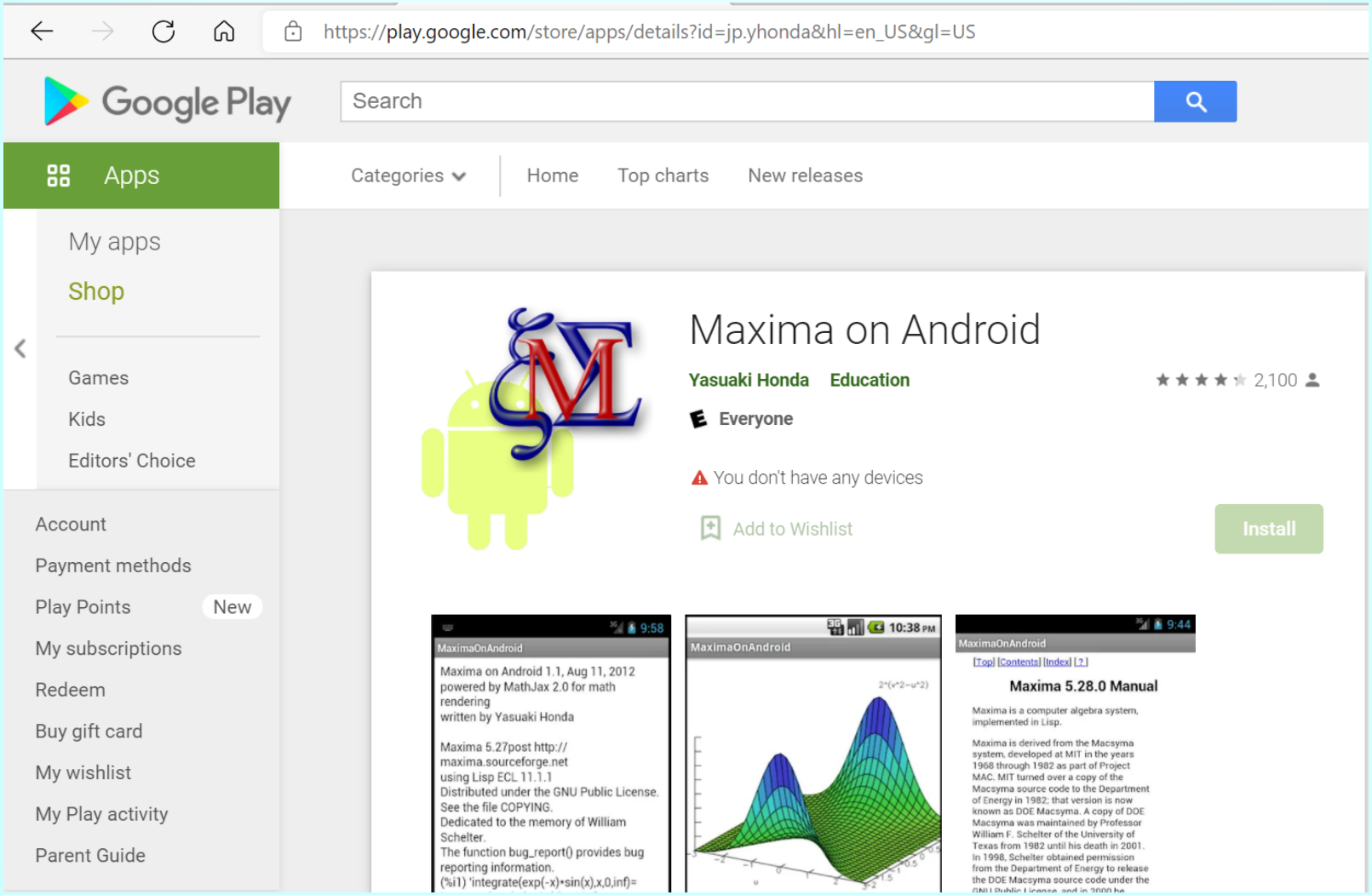
(%o2) $\left[x=-\frac{\sqrt{7}\,i-1}{2},x=\frac{\sqrt{7}\,i+1}{2}\right]$

(%i3) invert(matrix([2,3,1], [a,0,0], [1,4,8]));

(%o3) $\begin{pmatrix} 0 & \frac{1}{a} & 0 \\ \frac{2}{5} & -\frac{3}{4\,a} & -\frac{1}{20} \\ -\frac{1}{5} & \frac{1}{4\,a} & \frac{3}{20} \end{pmatrix}$

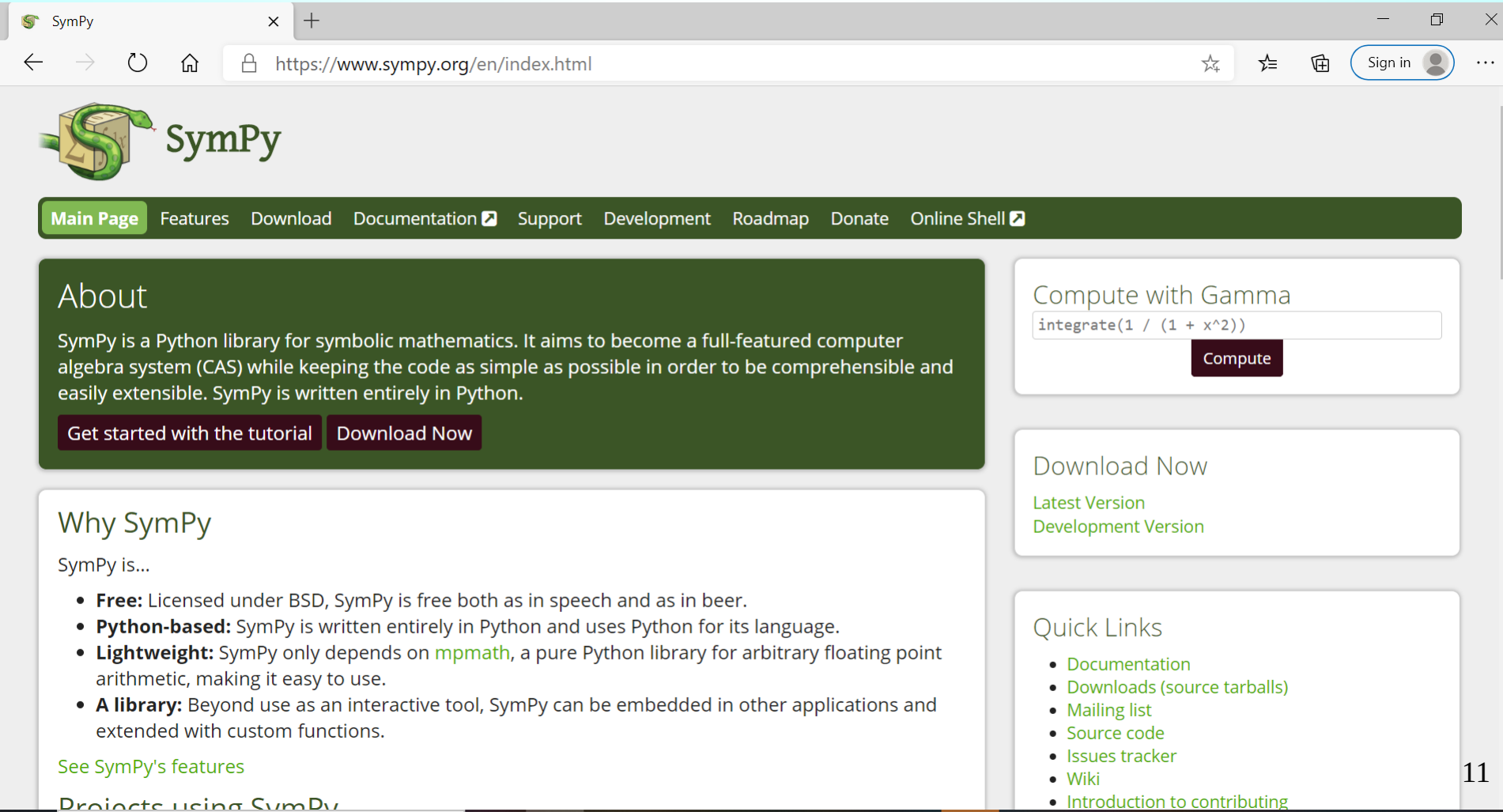
# Maxima on Android

**https://play.google.com/store/apps/details?id=jp.yhonda&hl=en_US&gl=US**



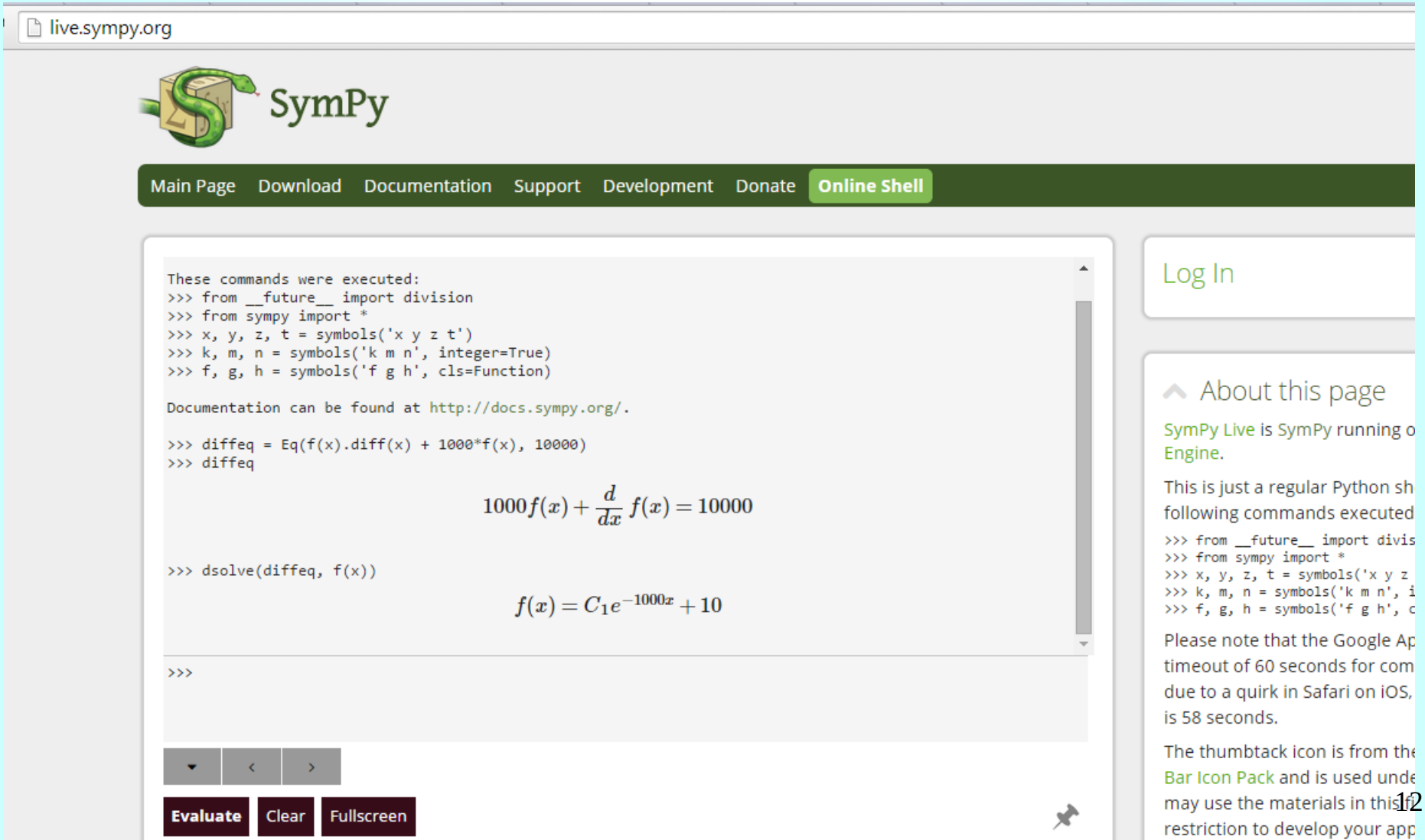
# SymPy

## www.sympy.org/



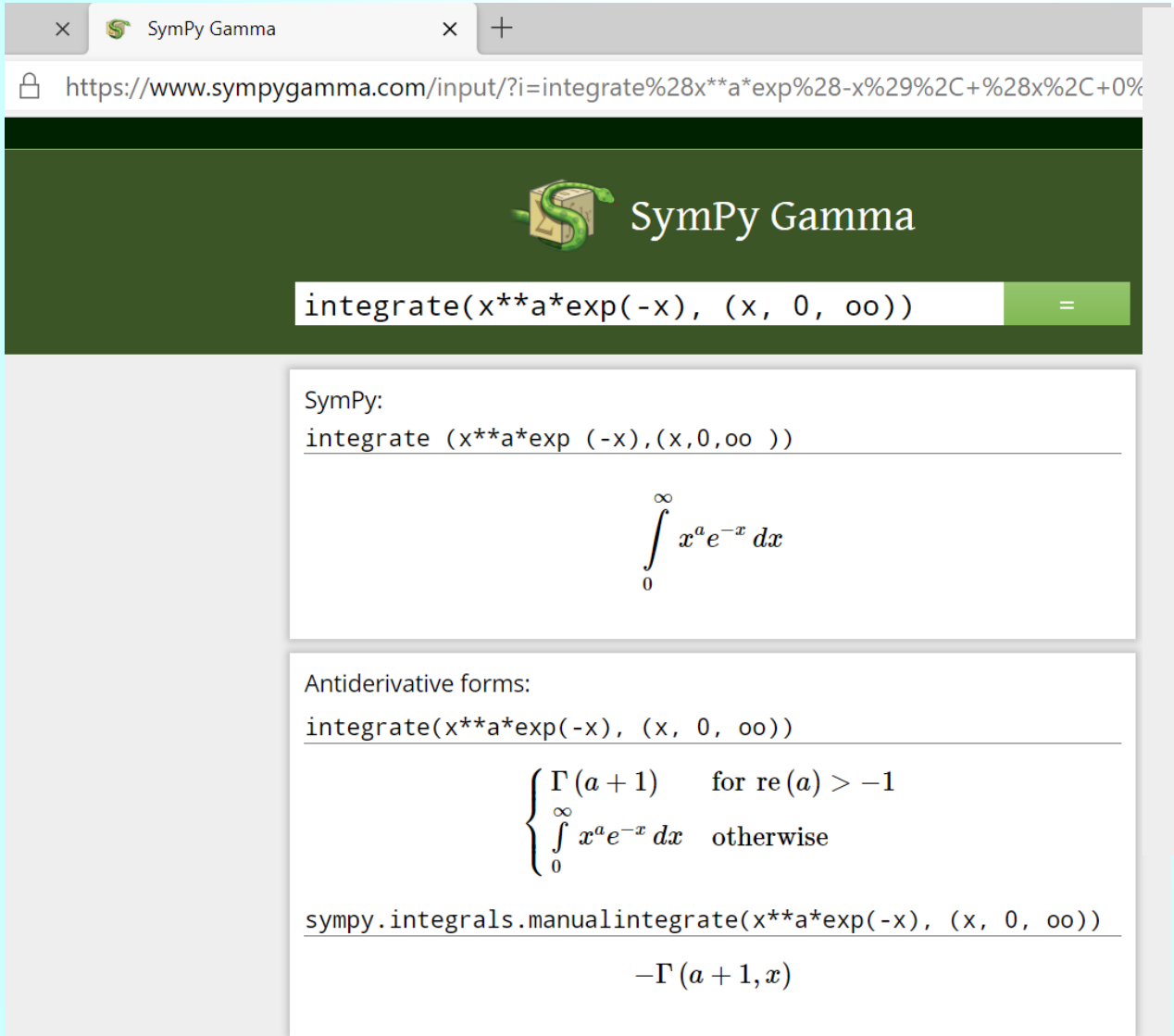
# SymPy live

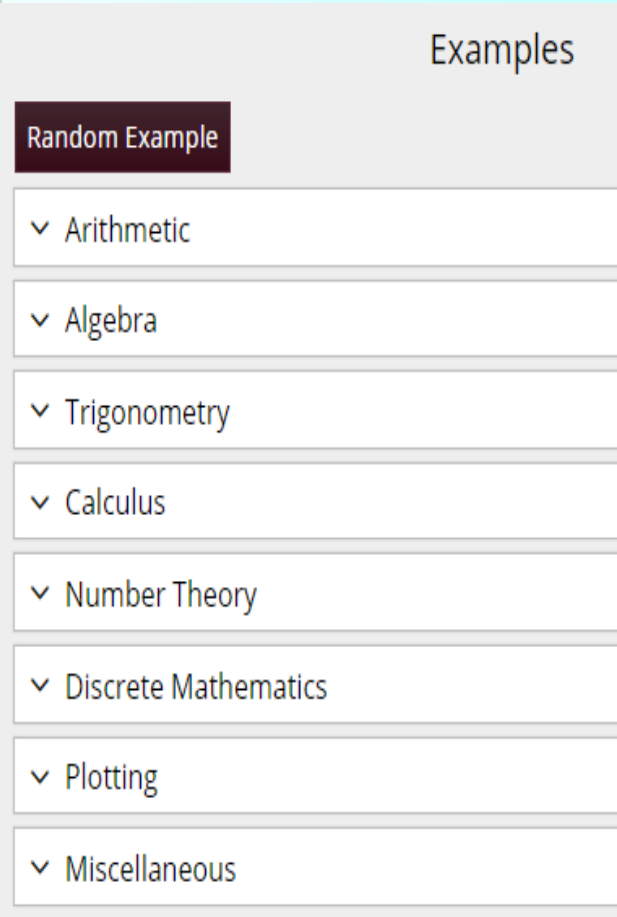
## live.sympy.org

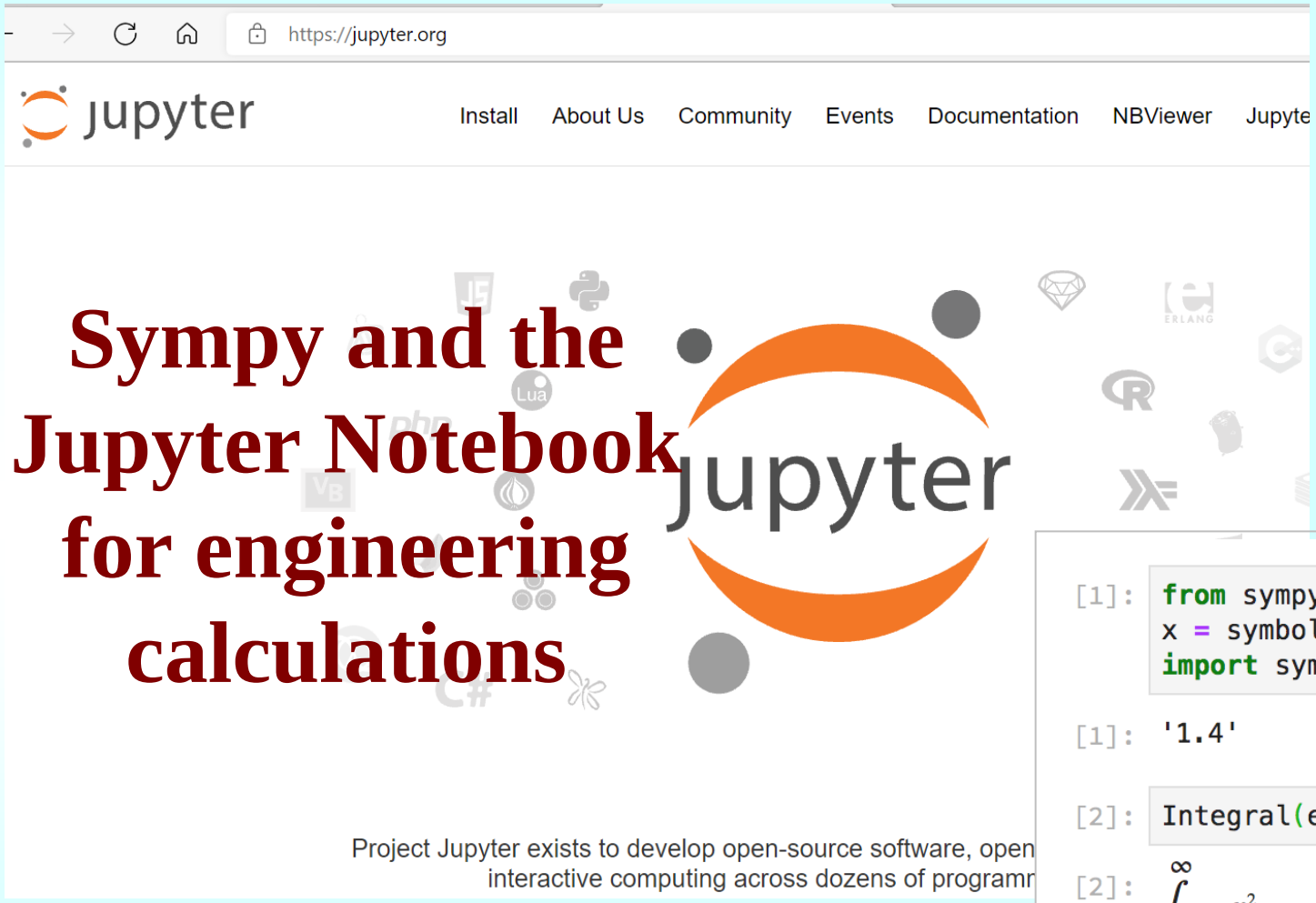


# SymPy Gamma

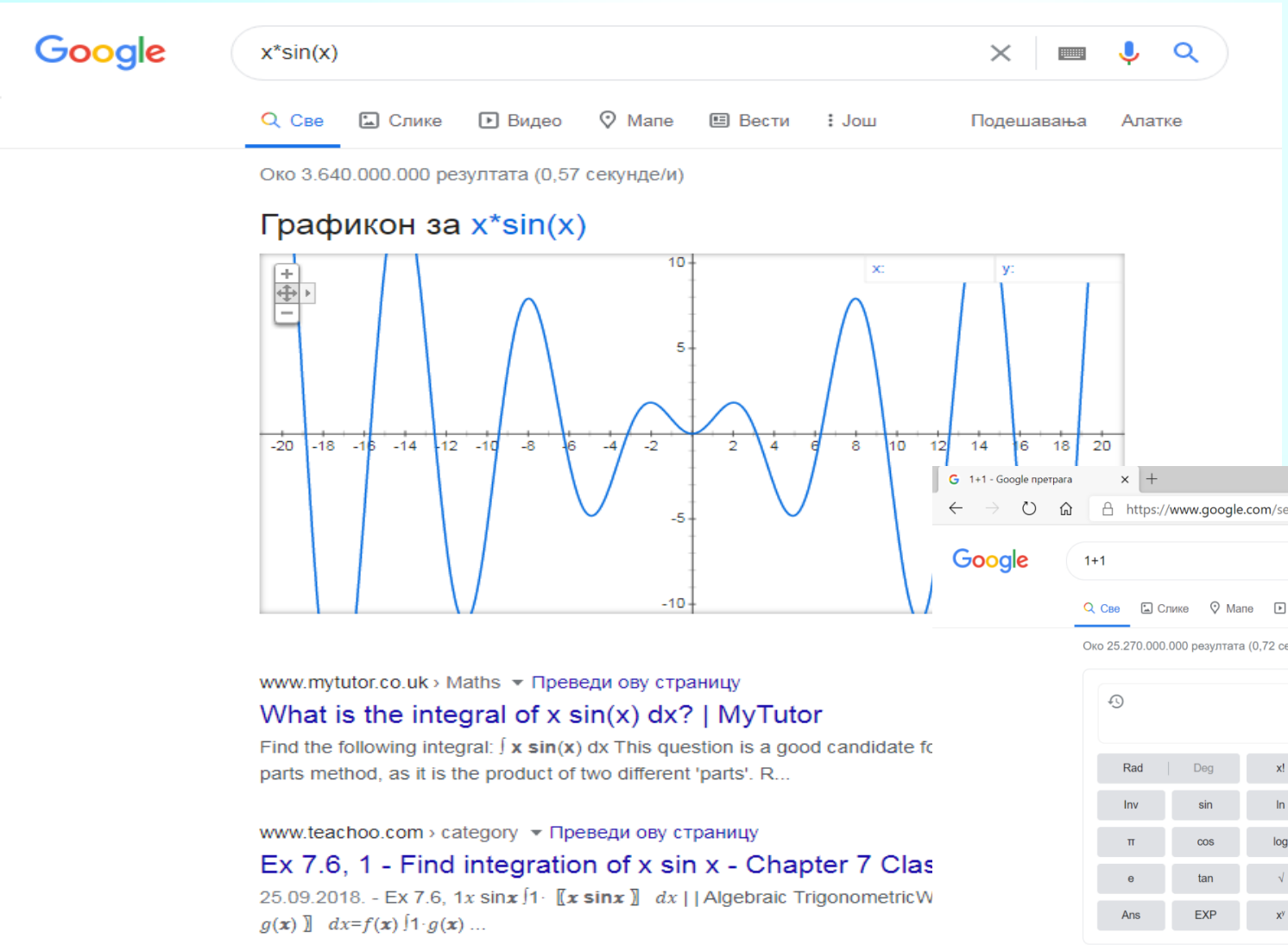
## https://www.sympygamma.com/

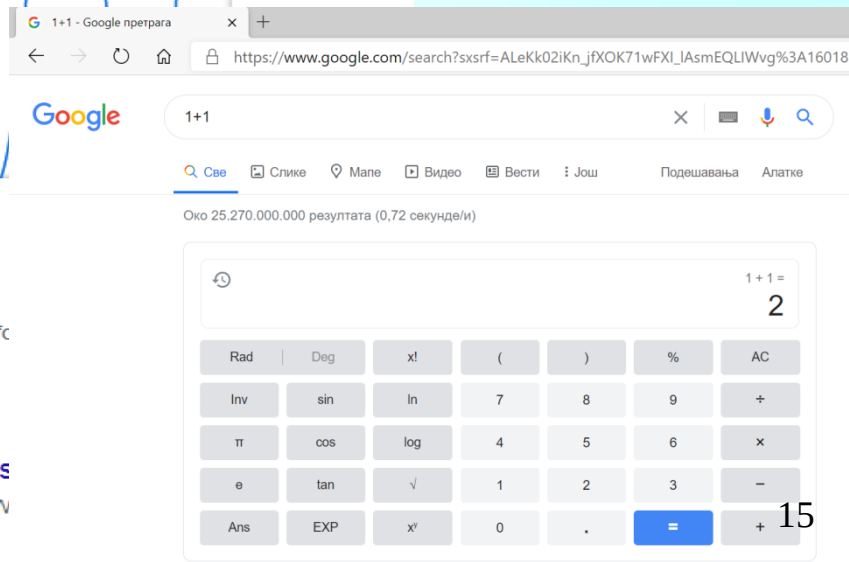



https://jupyter.org
jupyter
Install
About Us
Community
Events
Documentation
NBViewer
Jupyte
Sympy and the Jupyter Notebook for engineering calculations
jupyter
Project Jupyter exists to develop open-source software, open
interactive computing across dozens of programm
[1]: from sympy import *
x = symbols('x')
import sympy;sympy.__version__
[1]: '1.4'
[2]: Integral(exp(-x**2), (x, -oo, oo))
[2]: $\int_{-\infty}^{\infty} e^{-x^2}\,dx$
[3]: _.doit()
[3]: $\sqrt{\pi}$

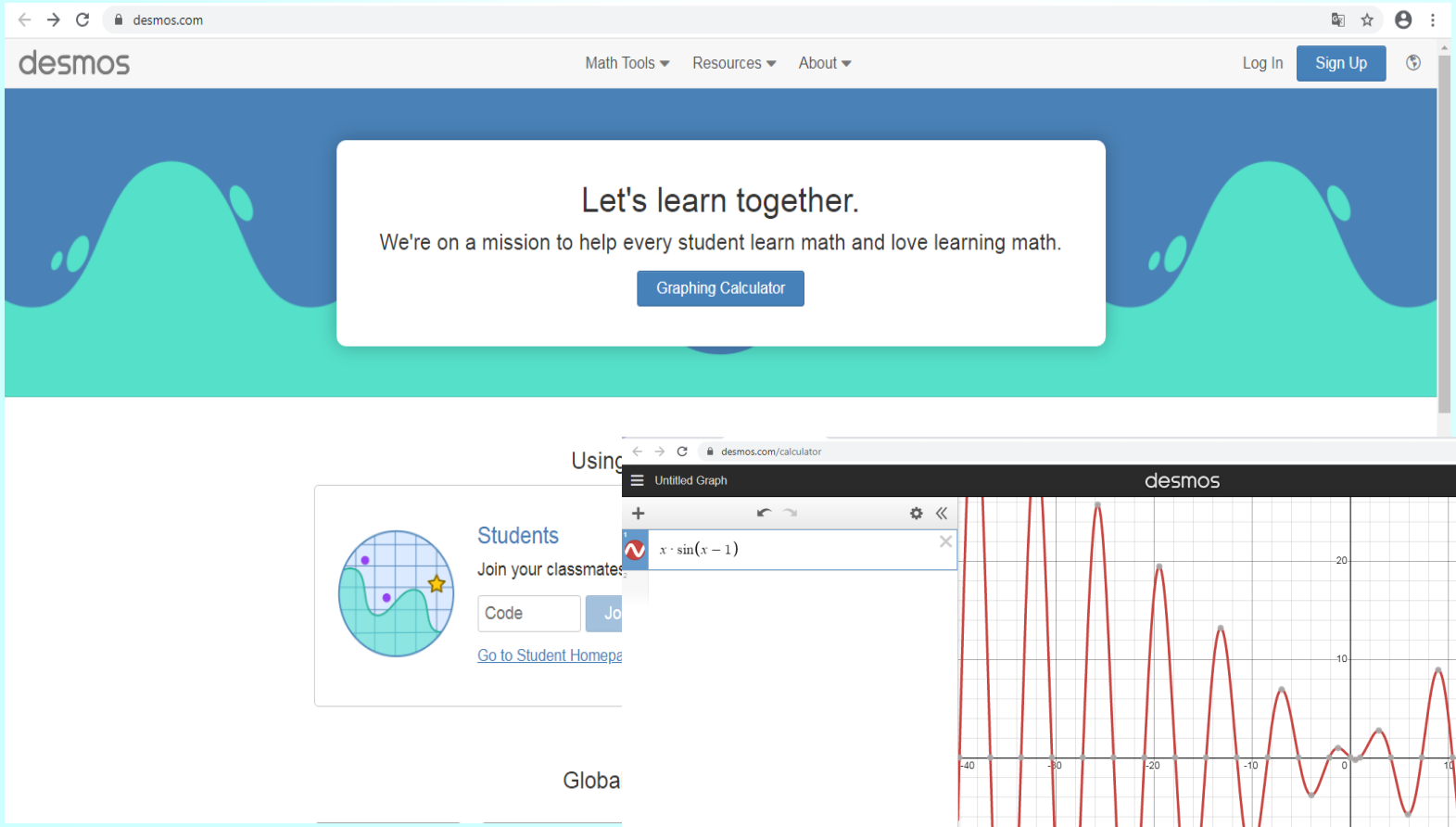
# Google калкулатор

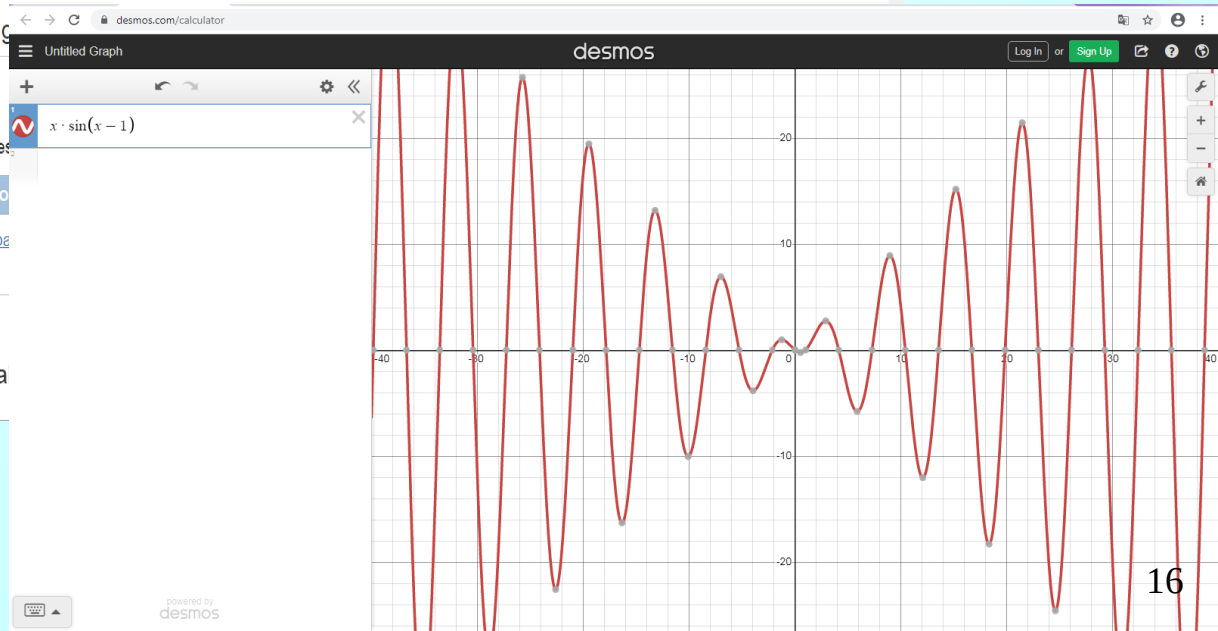


# Graphing Calculator – Desmos

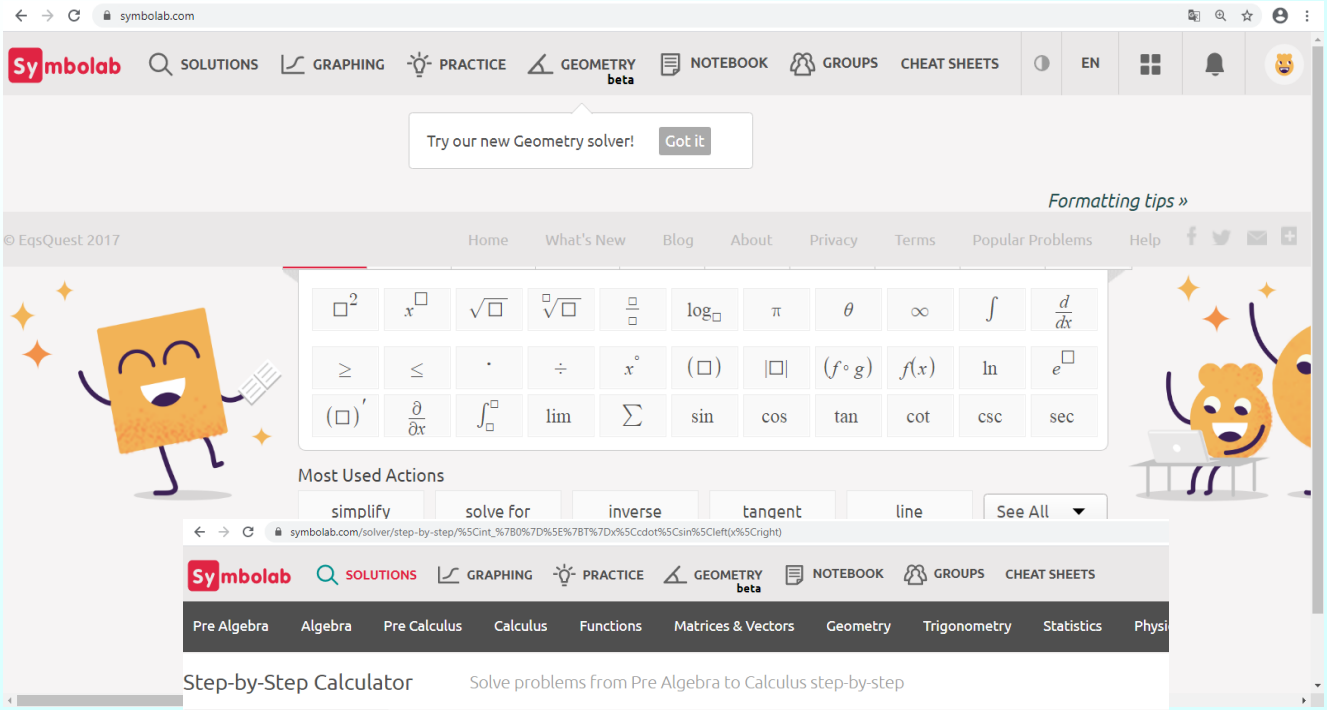
## https://www.desmos.com/calculator

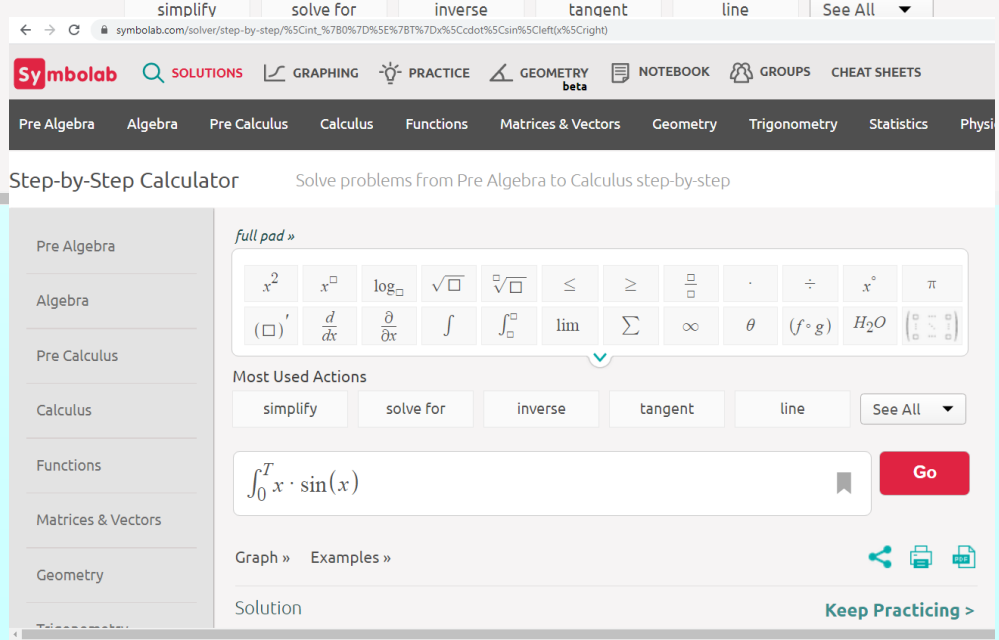


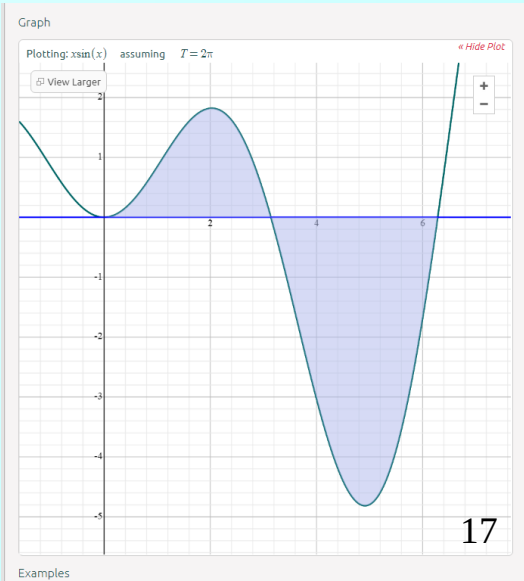
# Symbolab Math Solver - Step by Step calculator

## https://www.symbolab.com/



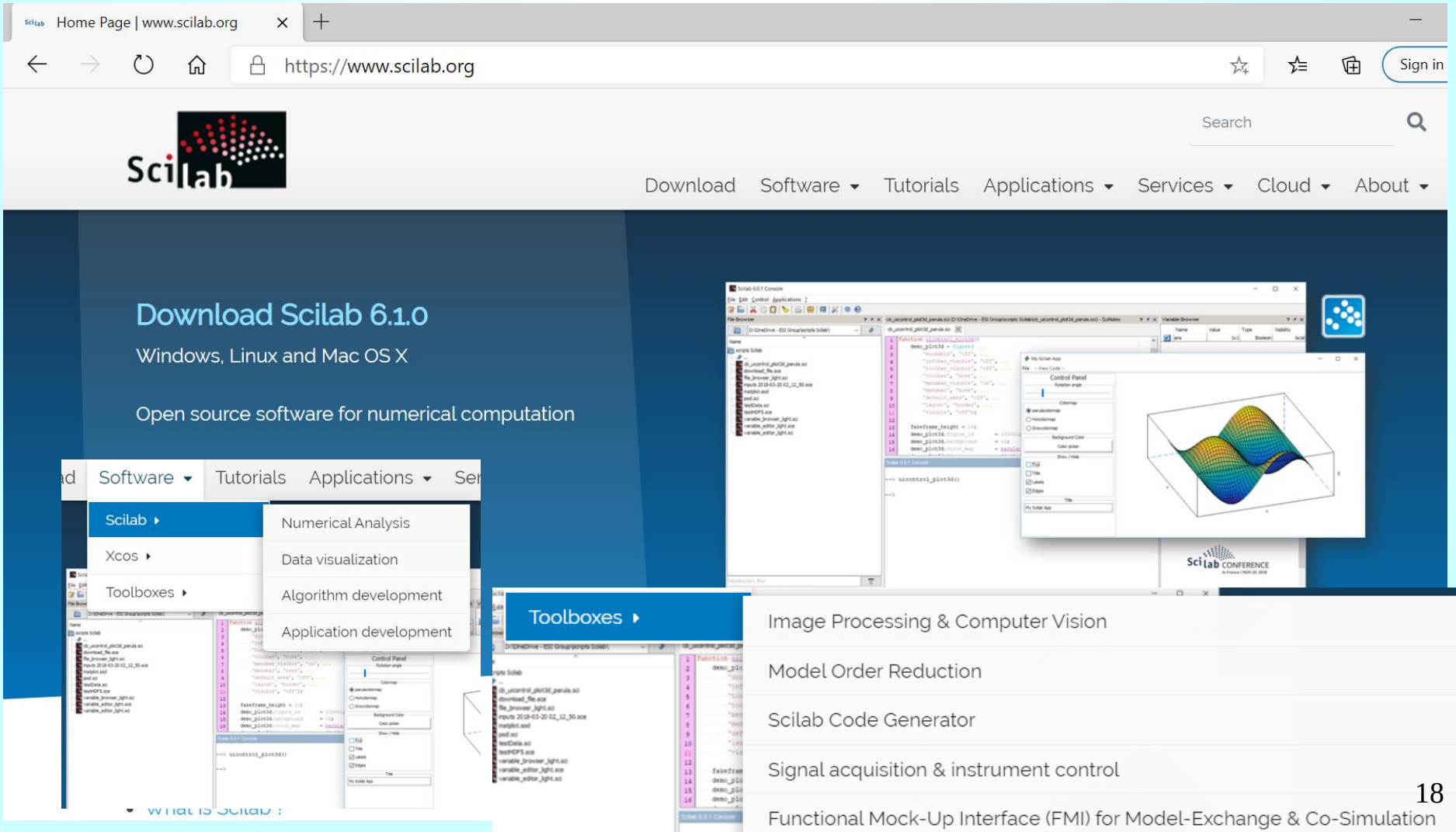







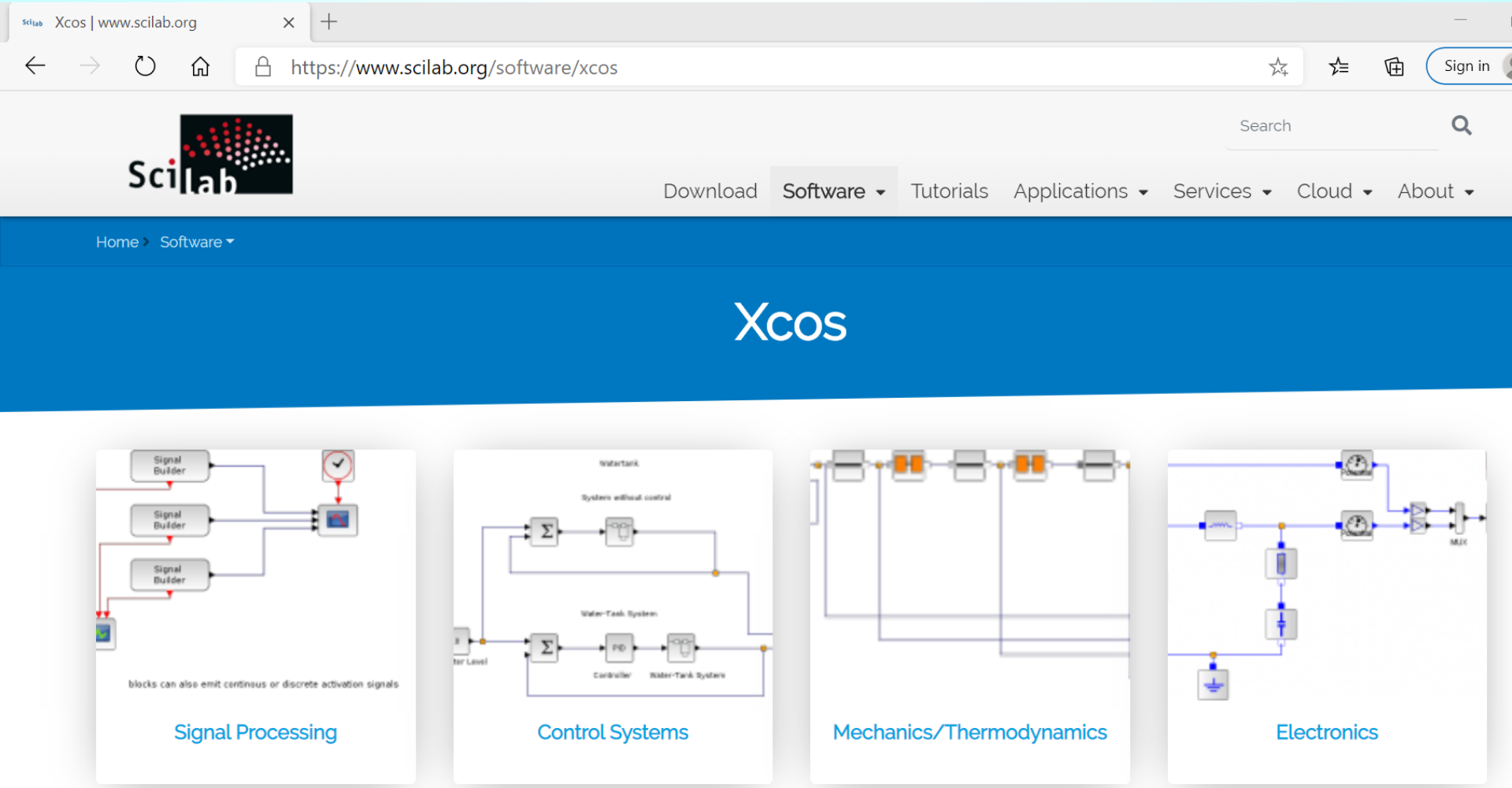
# SciLab

## https://www.scilab.org/



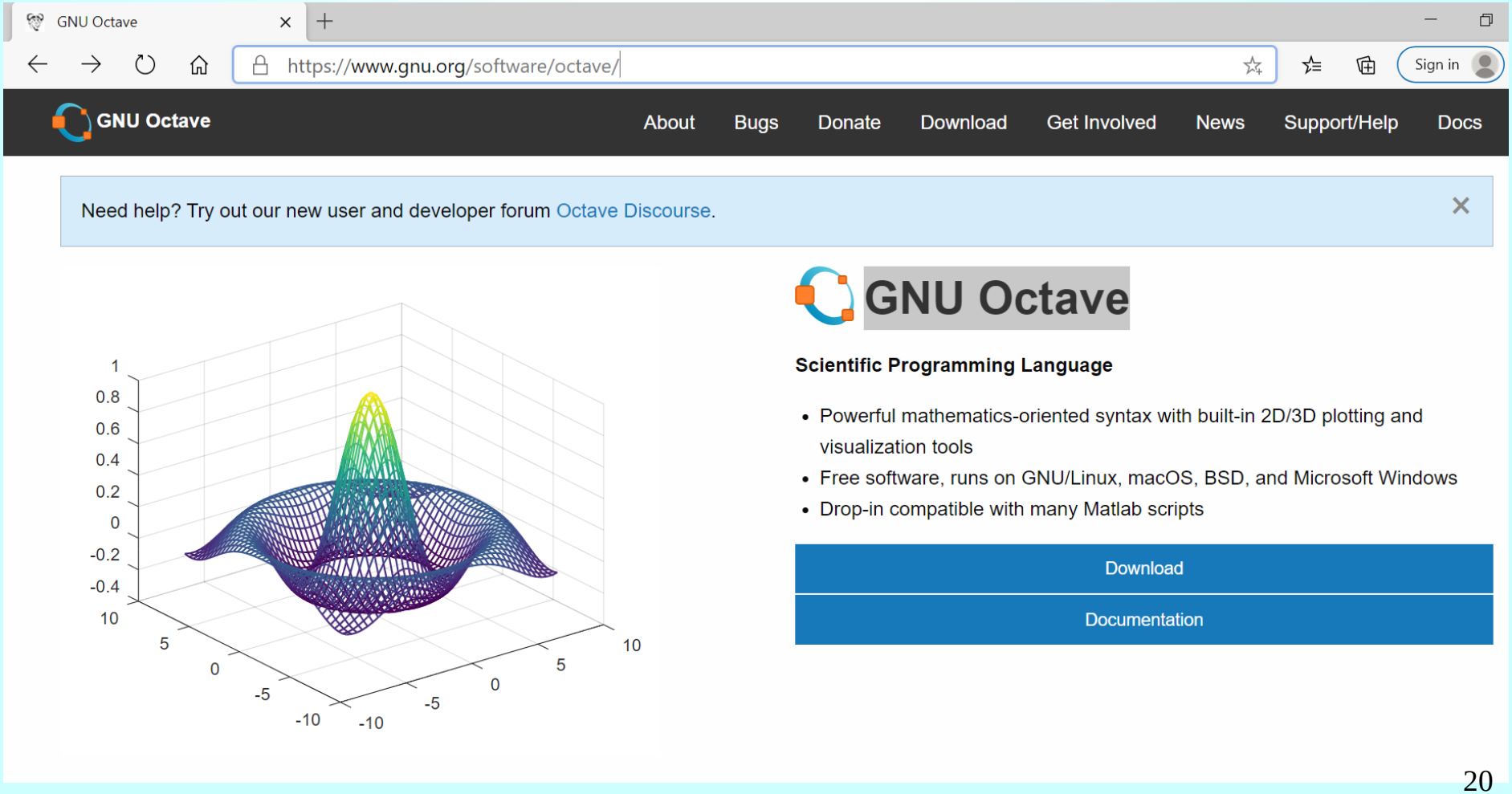
# Xcos

## https://www.scilab.org/software/xcos



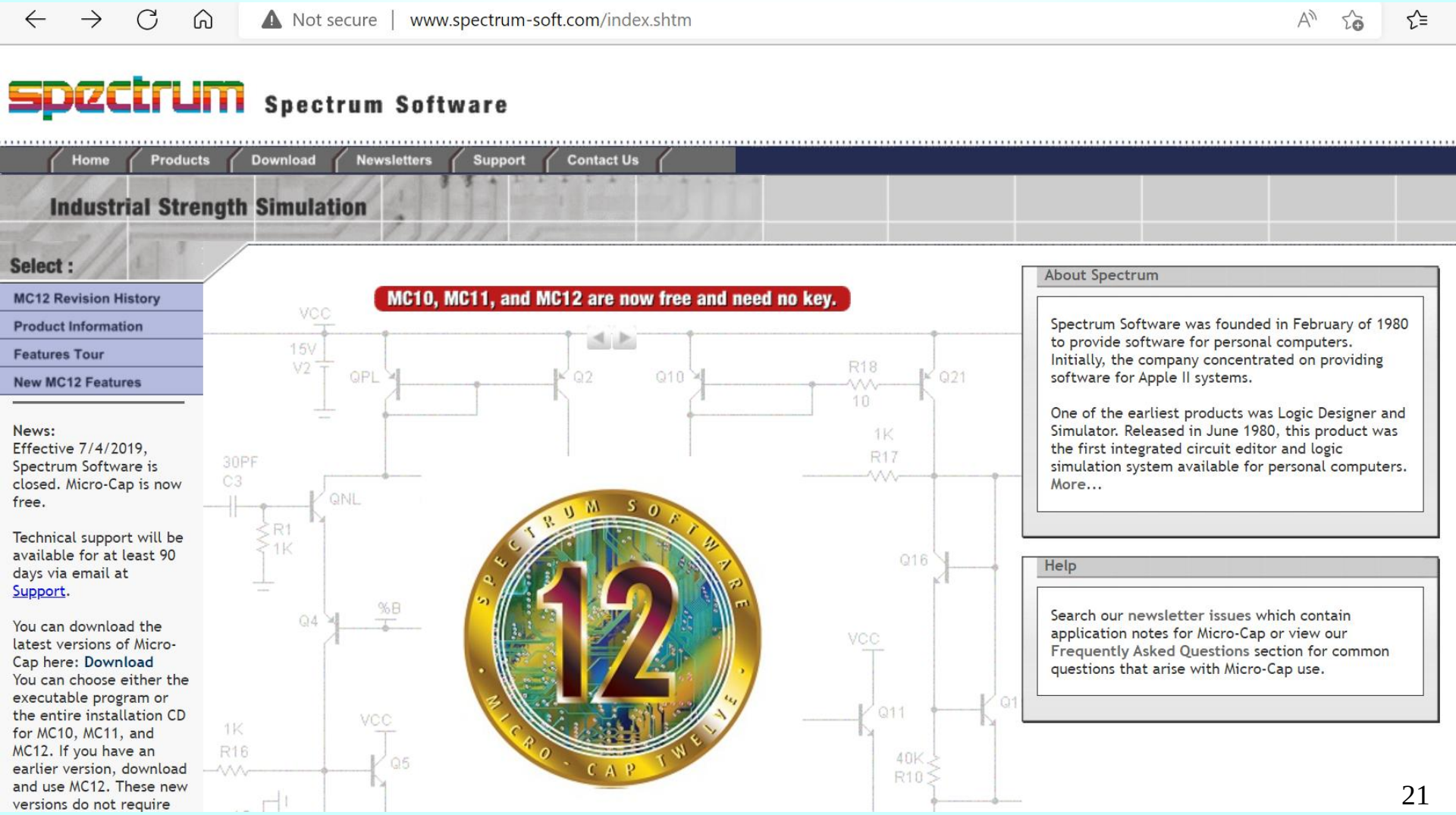
# GNU Octave

## https://www.gnu.org/software/octave/



# Micro-Cap

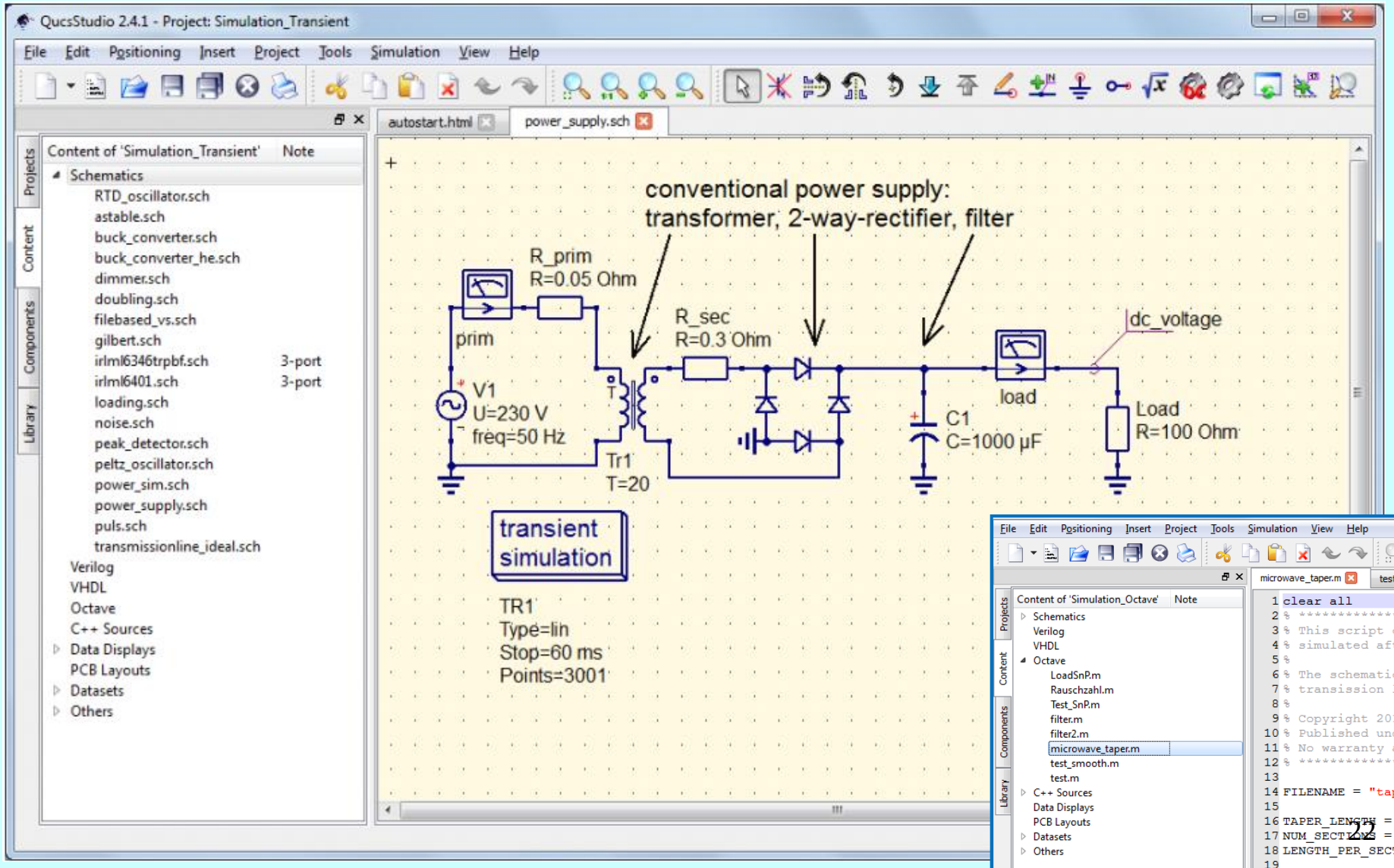
## http://www.spectrum-soft.com/index.shtm



# QucsStudio

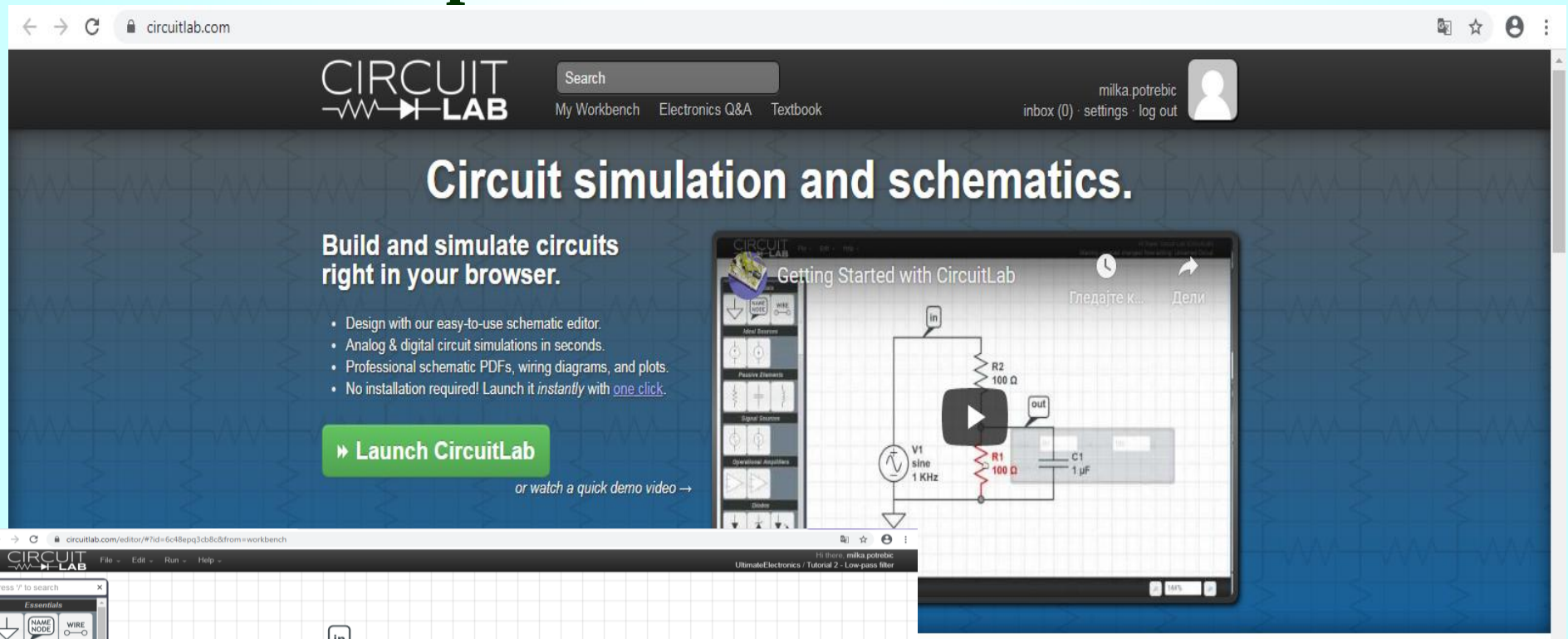
## http://qucsstudio.de

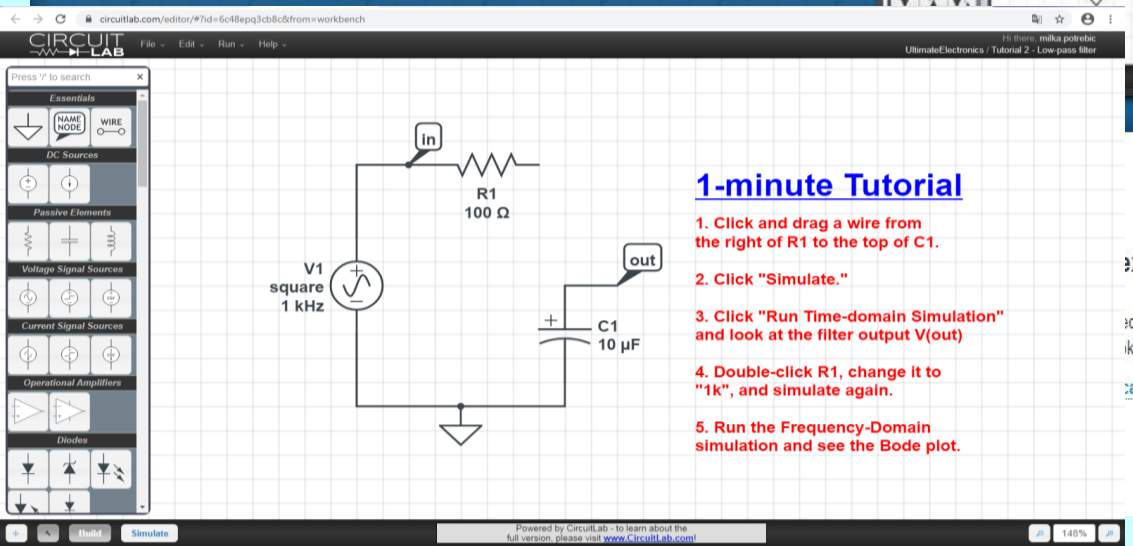
***Octave engine inside!***



# CircuitLab

## https://www.circuitlab.com/



# DoCircuits Circuit Simulator

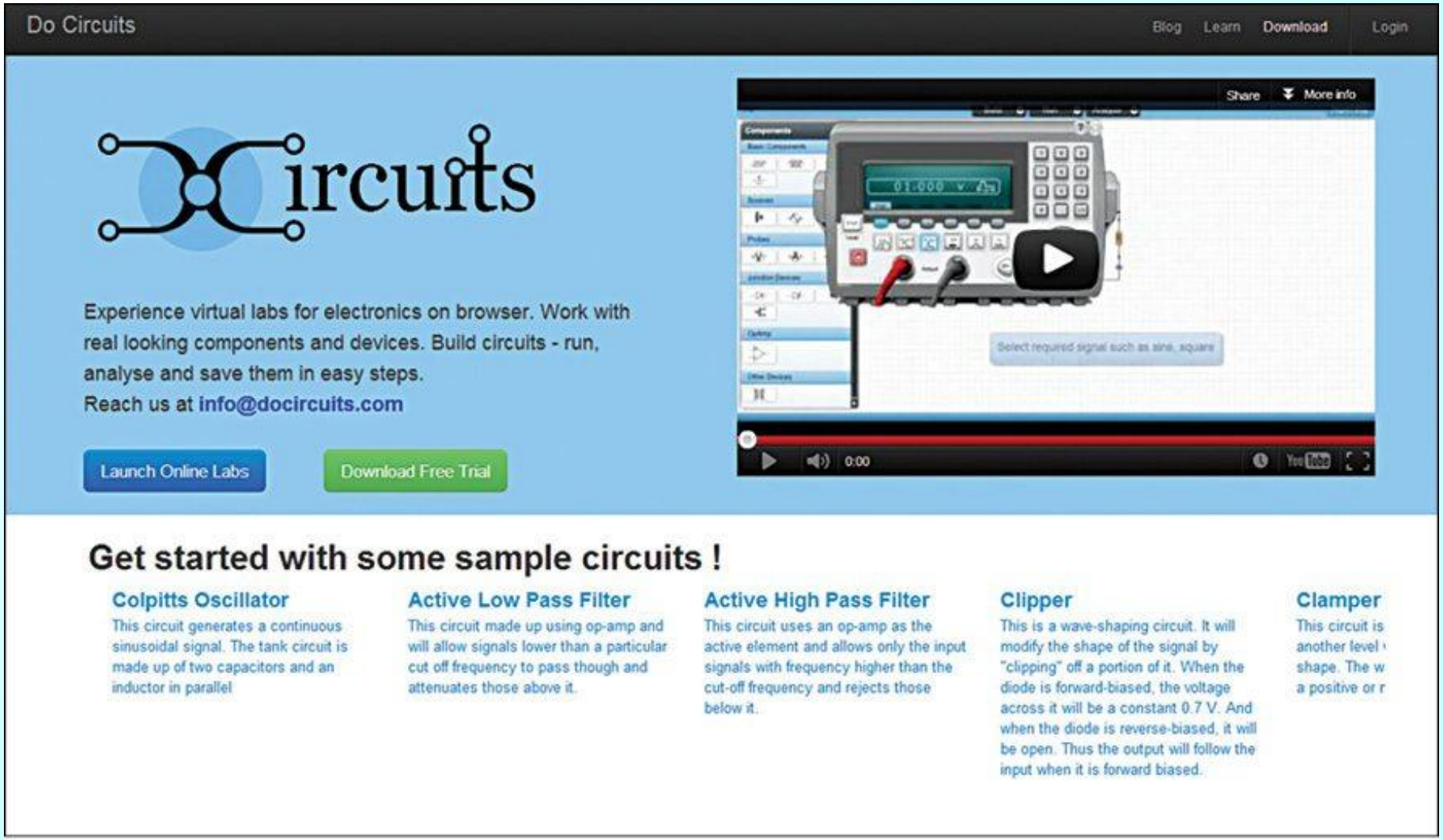



*Fig. 1: DoCircuits - Home*

# ngSpice

## http://ngspice.sourceforge.net/

Not secure | ngspice.sourceforge.net

NGSPICE

MIXED MODE - MIXED LEVEL CIRCUIT SIMULATOR

BASED ON BERKELEY'S SPICE3F5

NGSPICE SUMMARY

Home | News | Screenshots | Download | Documentation | Tutorials | Extras/Options | Applications | Development | Simulation Environments | Recipes

**Ngspice Home**

- Home
- What is ngspice ?
- Features, Extras & Options
- F.A.Q.
- Tutorials

Sourceforge Developer Pages

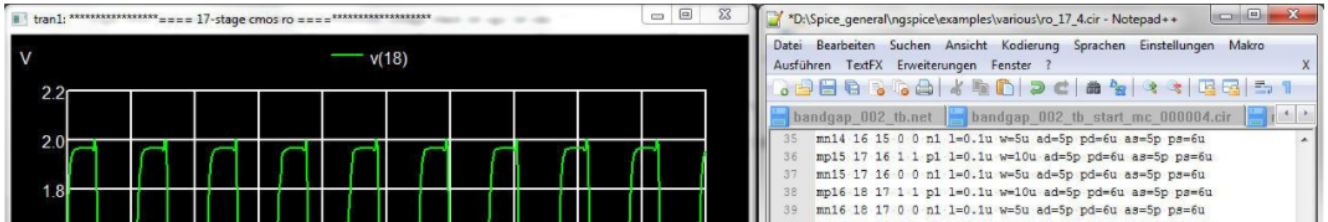
### ngspice - open source spice simulator

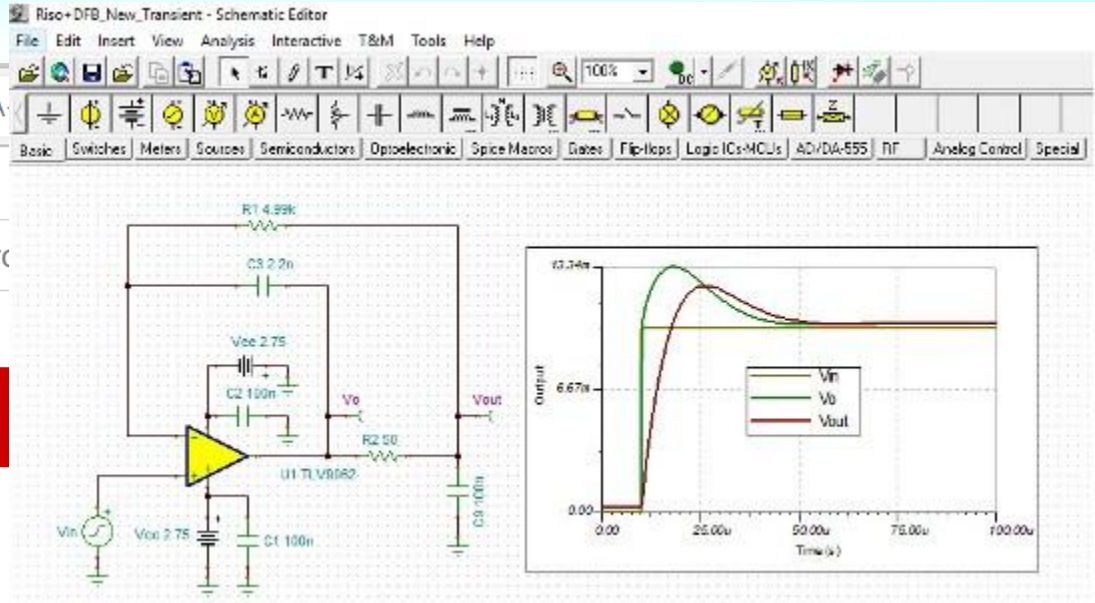
ngspice is the open source spice simulator for electric and electronic circuits.

Such a circuit may comprise of JFETs, bipolar and MOS transistors, passive elements like R, L, or C, diodes, transmission lines and other devices, all interconnected in a netlist. Digital circuits are simulated as well, event driven and fast, from single gates to complex circuits. And you may enter the combination of both analog and digital as a mixed-signal circuit.

ngspice offers a wealth of device models for active, passive, analog, and digital elements. Model parameters are provided by our collections, by the semiconductor device manufacturers, or from semiconductor foundries. The user adds her circuits as a netlist, and the output is one or more graphs of currents, voltages and other electrical quantities or is saved in a data file.

ngspice does not provide schematic entry. Its input is command line or file based. There are however third party interfaces available.






https://www.ti.com/tool/TINA-

TEXAS INSTRUMENTS

Search

Products Applications Design resources

Home / Design resources

# TINA-TI

## SPICE-based analog simulation program

Overview | Downloads | Technical documentation | Support & training

**TINA-TI**

**https://www.ti.com/tool/TINA-TI**

## Overview

TINA-TI provides all the conventional DC, transient and frequency domain analysis of SPICE and much more. TINA has extensive post-processing capability that allows you to format results the way you want them. Virtual instruments allow you to

# Electric Circuit Studio

https://play.google.com/store/apps/details?id=com.ecstudiosystems.electriccircuitstudio&hl=en_US&gl=US

Google Play

Search

Apps

Categories

Home

Top charts

New releases

My apps

Shop

Games

Kids

Editors' Choice

Account

Payment methods

Play Points New

My subscriptions

Redeem

Buy gift card

My wishlist

My Play activity

Parent Guide

Electric Circuit Studio

ECStudio Systems Education

2,709

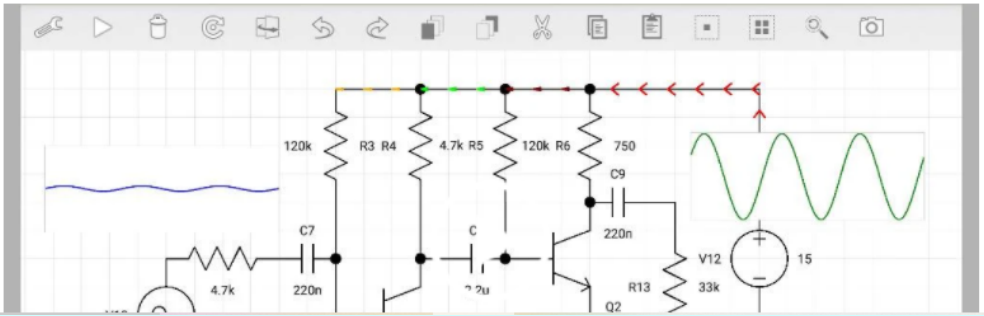
Everyone

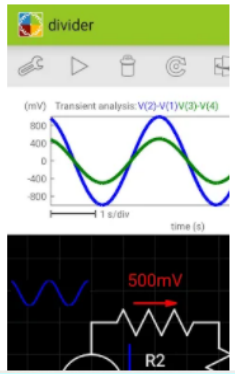
Contains Ads

You don't have any devices

Add to Wishlist

Install



# CircuitSafari SPICE Simulator

https://play.google.com/store/apps/details?id=com.logipipe.circuitsafari&hl=en_US&gl=US

Google Play

Search

Apps

Categories | Home | Top charts | New releases

My apps

Shop

Games

Kids

Editors' Choice

Account

Payment methods

Play Points New

My subscriptions

Redeem

Buy gift card

My wishlist

My Play activity

Parent Guide

## CircuitSafari SPICE Simulator (Early Access)

Logipipe, LLC Productivity

Everyone

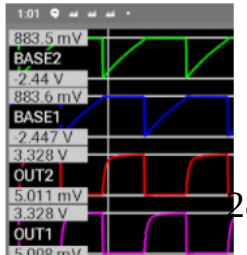
Offers in-app purchases

This app is in development. It may be unstable.

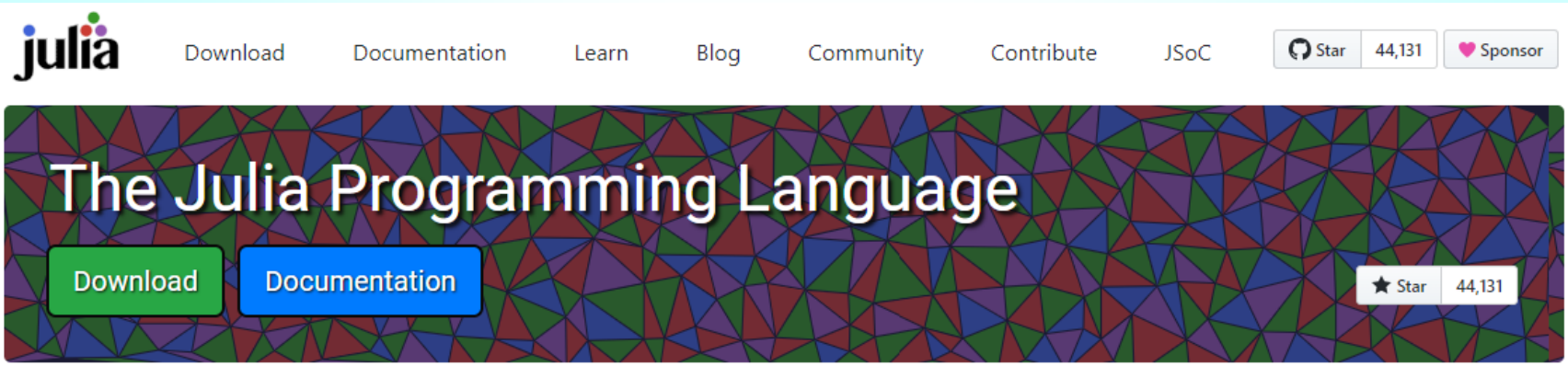
You don't have any devices

Add to Wishlist

Install



# Julia Programming Language




## Julia in a Nutshell

### Fast

Julia was designed for high performance. Julia programs automatically compile to efficient native code via LLVM, and support multiple platforms.

### Dynamic

Julia is dynamically typed, feels like a scripting language, and has good support for interactive use, but can also optionally be separately compiled.

### Reproducible

Reproducible environments make it possible to recreate the same Julia environment every time, across platforms, with pre-built binaries.

### Composable

Julia uses multiple dispatch as a paradigm, making it easy to express many object-oriented and functional programming patterns. The talk on the Unreasonable Effectiveness of Multiple Dispatch explains why it works so well.

### General

Julia provides asynchronous I/O, metaprogramming, debugging, logging, profiling, a package manager, and more. One can build entire Applications and Microservices in Julia.

### Open source

Julia is an open source project with over 1,000 contributors. It is made available under the MIT license. The source code is available on GitHub.

# MATLAB

MathWorks - Makers of MATLAB

https://www.mathworks.com

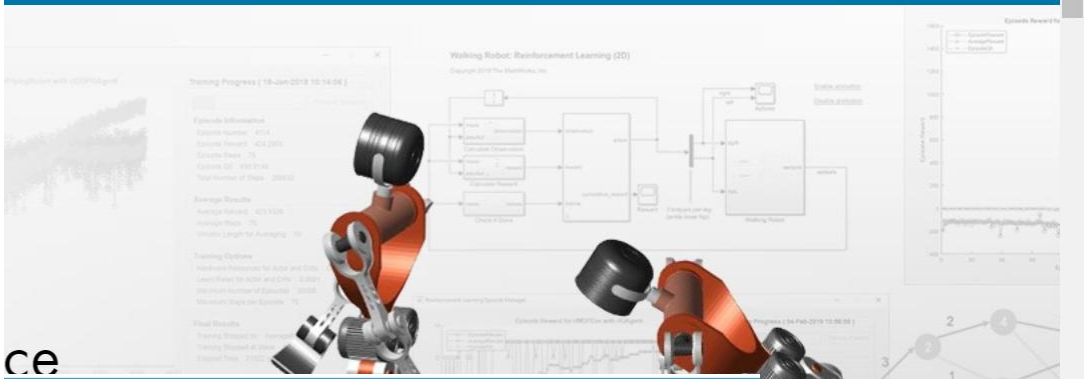
Sign in

MathWorks® Products Solutions Academia Support Community Events Get MATLAB

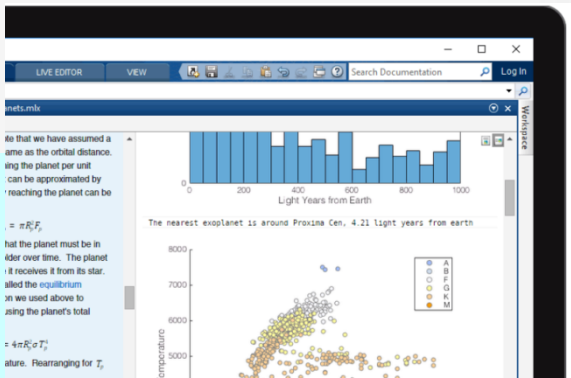
Search MathWorks.com

## Millions of Engineers and Scientists Trust MATLAB

MATLAB® combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. It includes the Live Editor for creating scripts that combine code, output, and formatted text in an executable notebook.



Design AI models and AI-driven systems



Search MathWorks.com

Products by Category | Alphabetical

Trial software

**MATLAB® PRODUCT FAMILY**

MATLAB

Parallel Computing
- Parallel Computing Toolbox
- MATLAB Parallel Server

Math and Optimization
- Curve Fitting Toolbox
- Optimization Toolbox
- Global Optimization Toolbox
- Symbolic Math Toolbox
- Mapping Toolbox

**SIMULINK® PRODUCT FAMILY**

Simulink
- System Composer

Event-Based Modeling
- Stateflow
- SimEvents

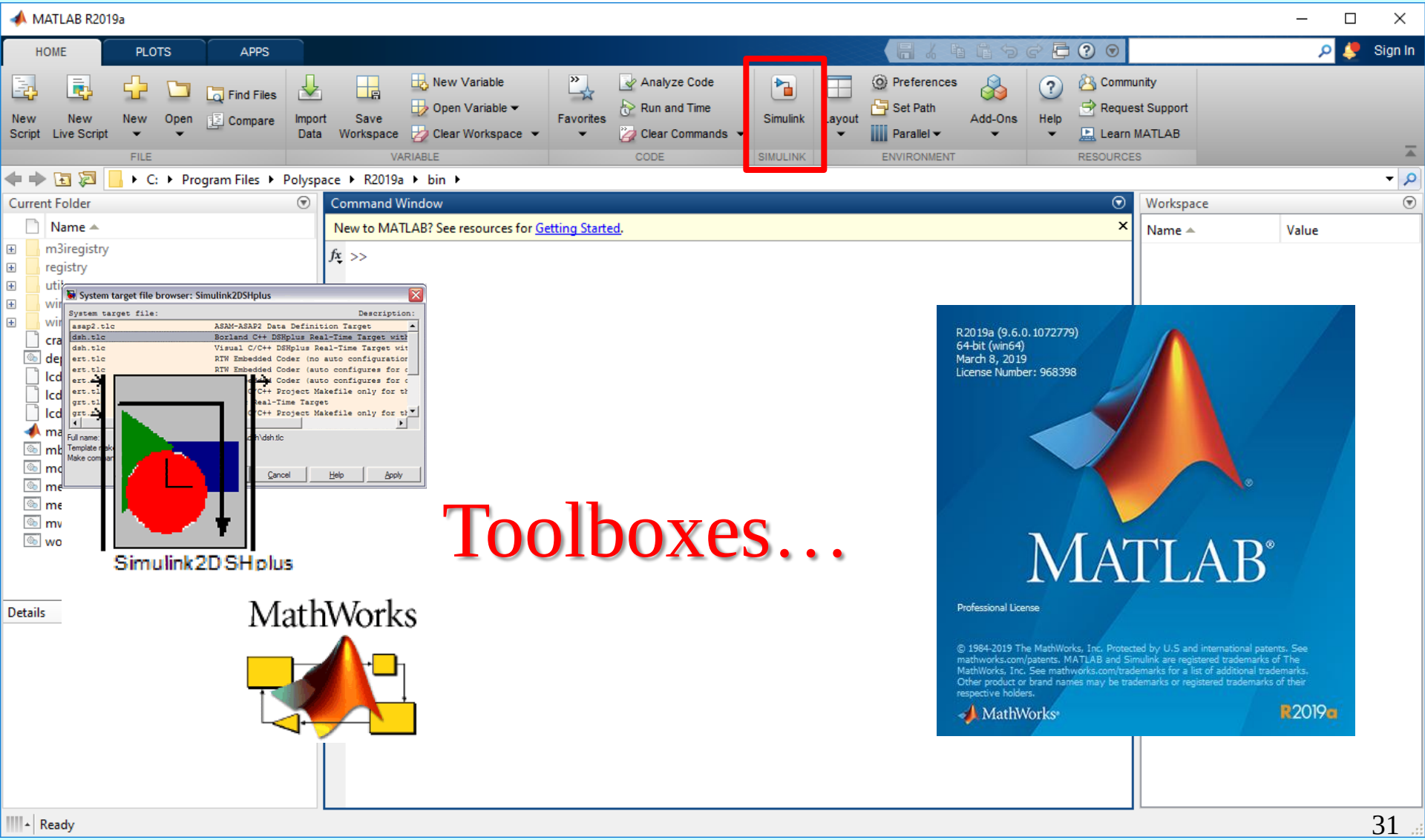
Physical Modeling
- Simscape
- Simscape Driveline
- Simscape Electrical
- Simscape Fluids

**SERVICES**
- Software Maintenance
- Training
- Consulting

**LICENSE TYPES**
- Industry Use
- Student Use
- University Use
- Startup Use
- Primary and Secondary School Use
- Home Use

# MATLAB

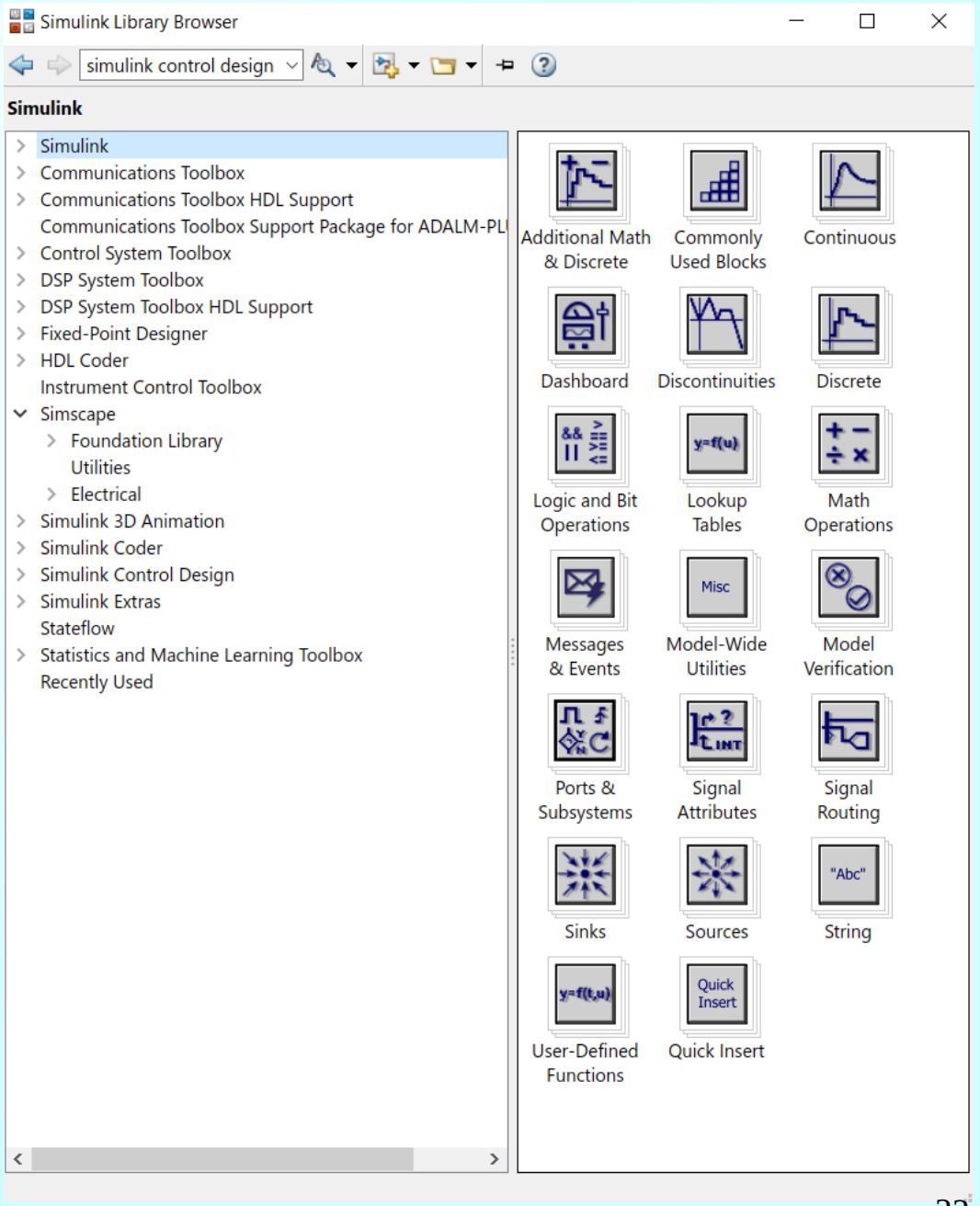
http://www.mathworks.com/




Toolboxes…

# MATLAB Simulink

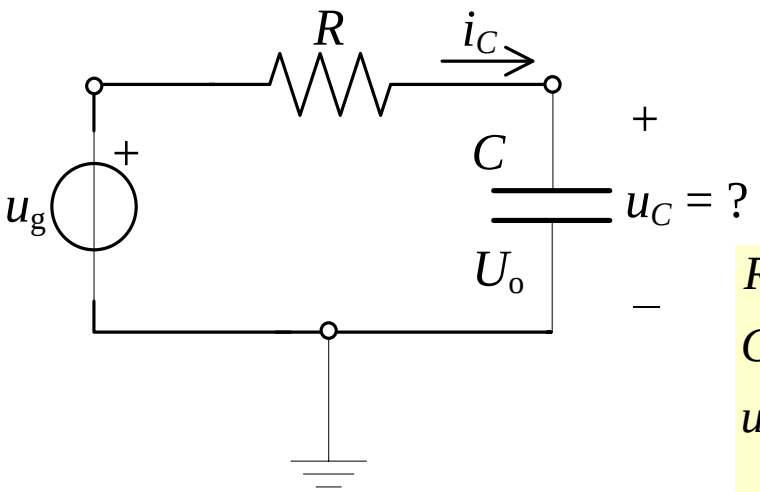
- Алатка за нумеричку анализу математичких модела
- Систем се дефинише графички, уметањем блокова и њиховим повезивањем у мрежу



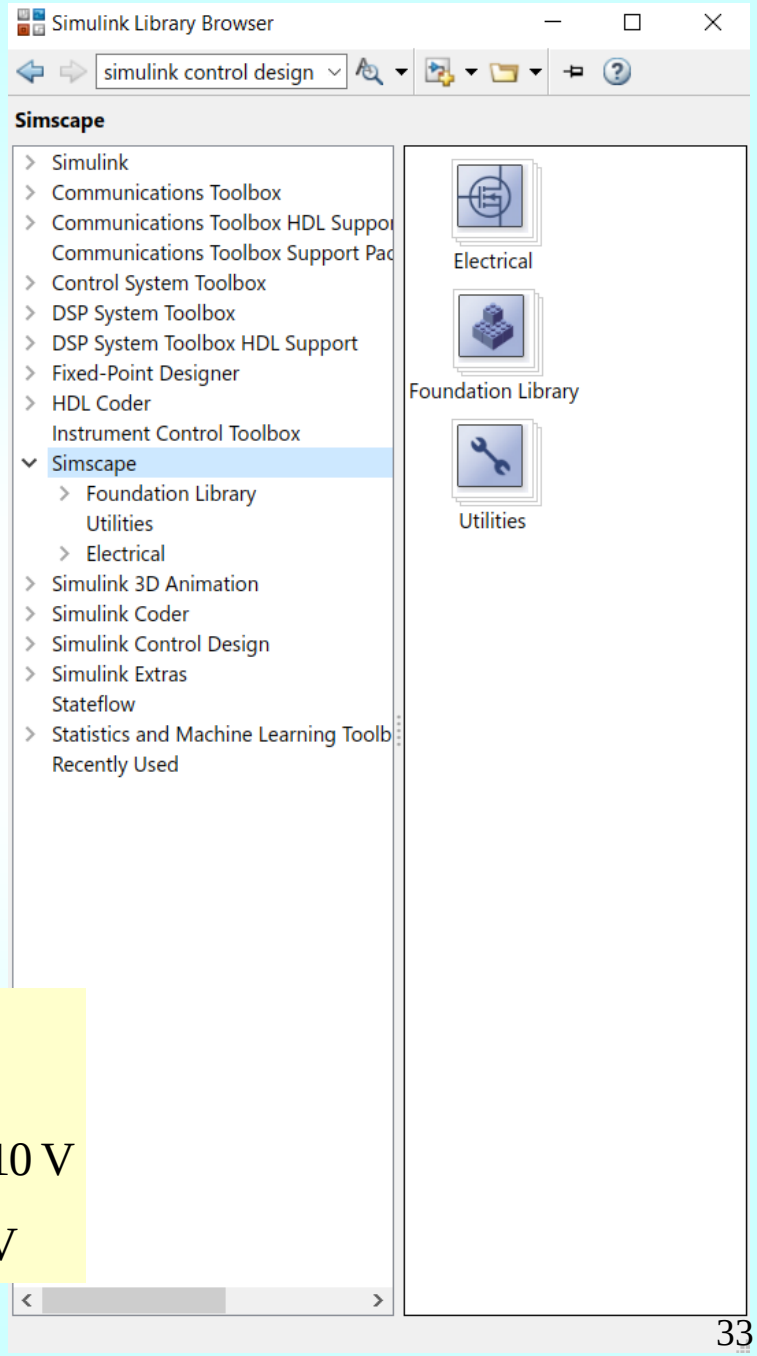
# Simulink > Simscape

- Библиотека за симулацију и нумеричку анализу мултидоменских проблема (механика, електродинамика, оптика)
- Пример једноставног електричног кола:

коло је образовано у тренутку $t_0 = 0$

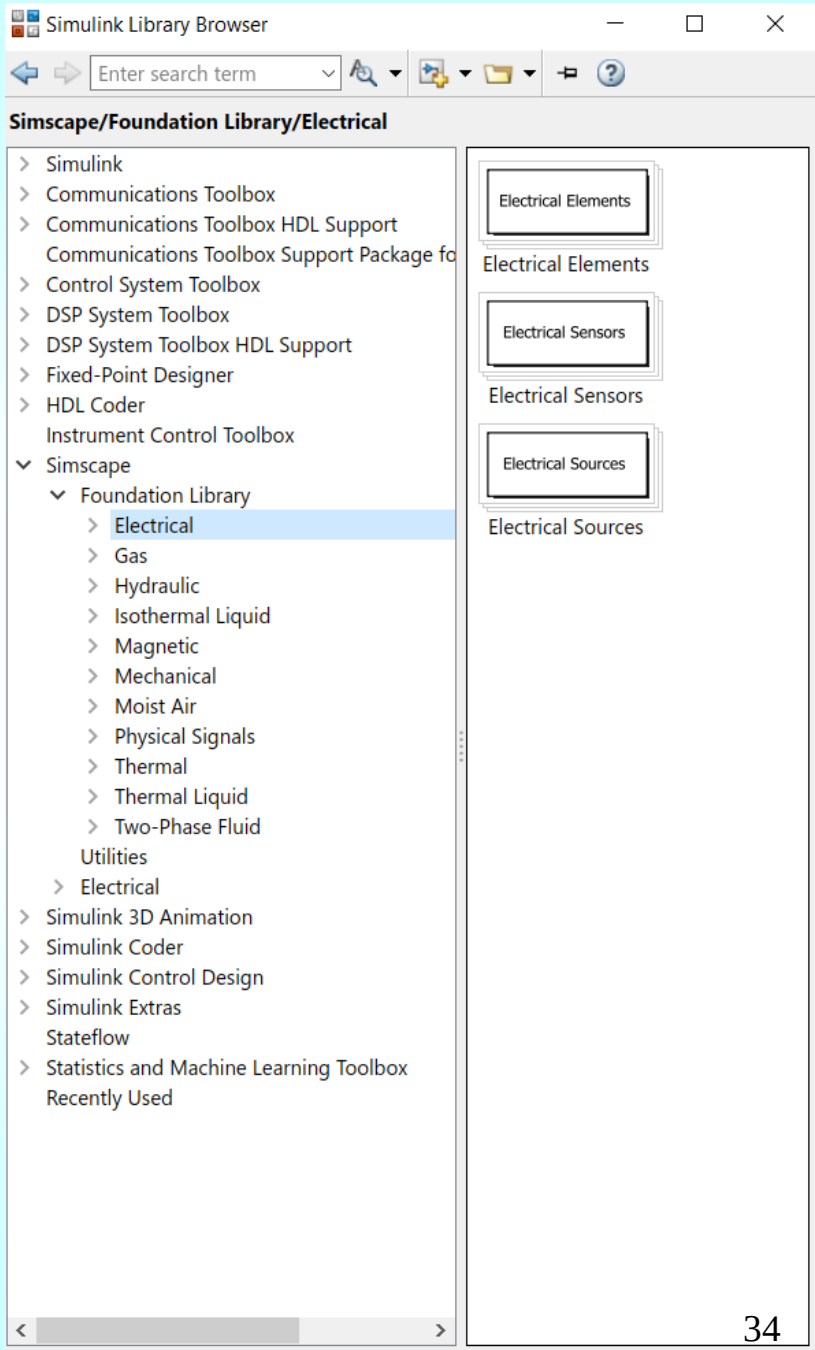



$$R = 1\,\mathrm{k\Omega}$$
$$C = 1\,\mu\mathrm{F}$$
$$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$



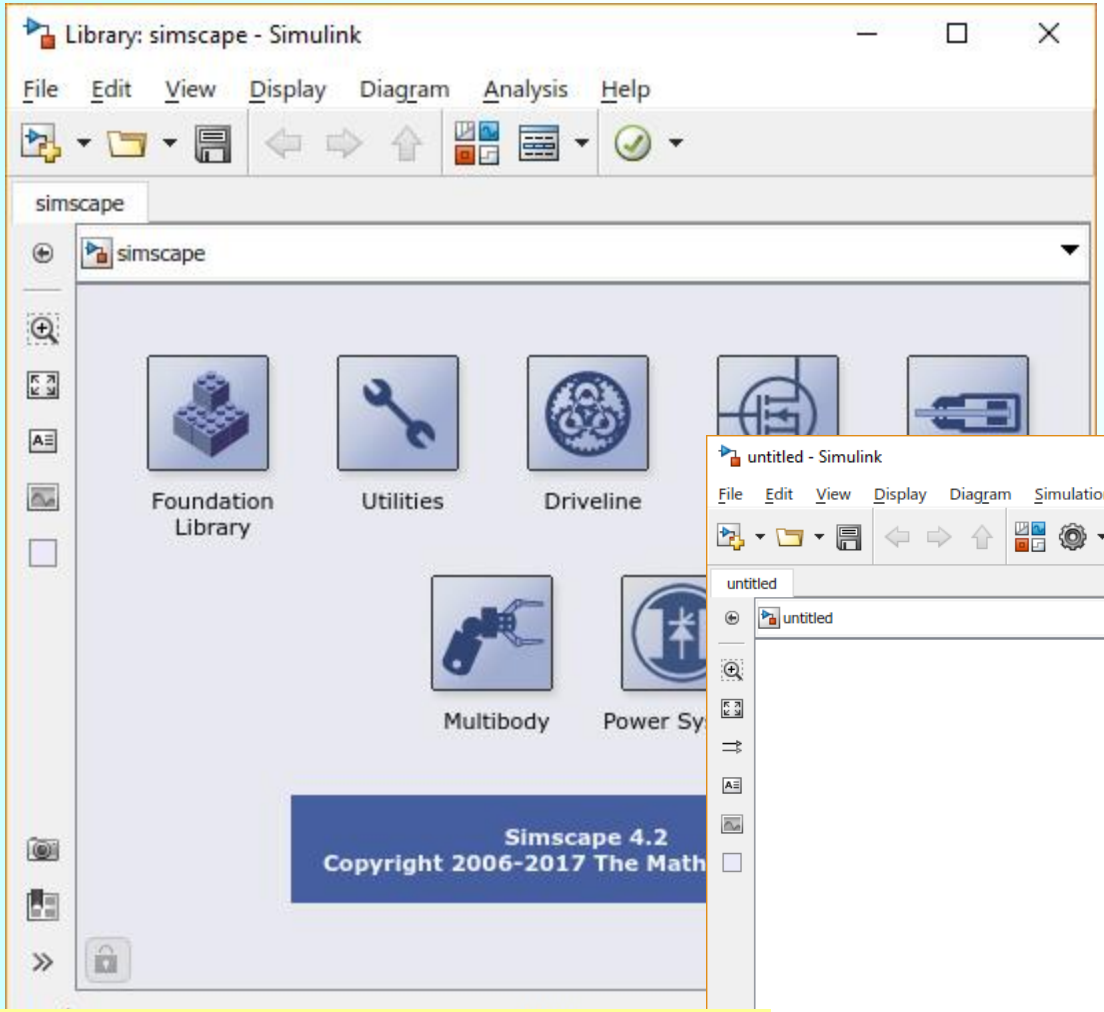
# Simulink > Simscape > Foundation Library > Electrical

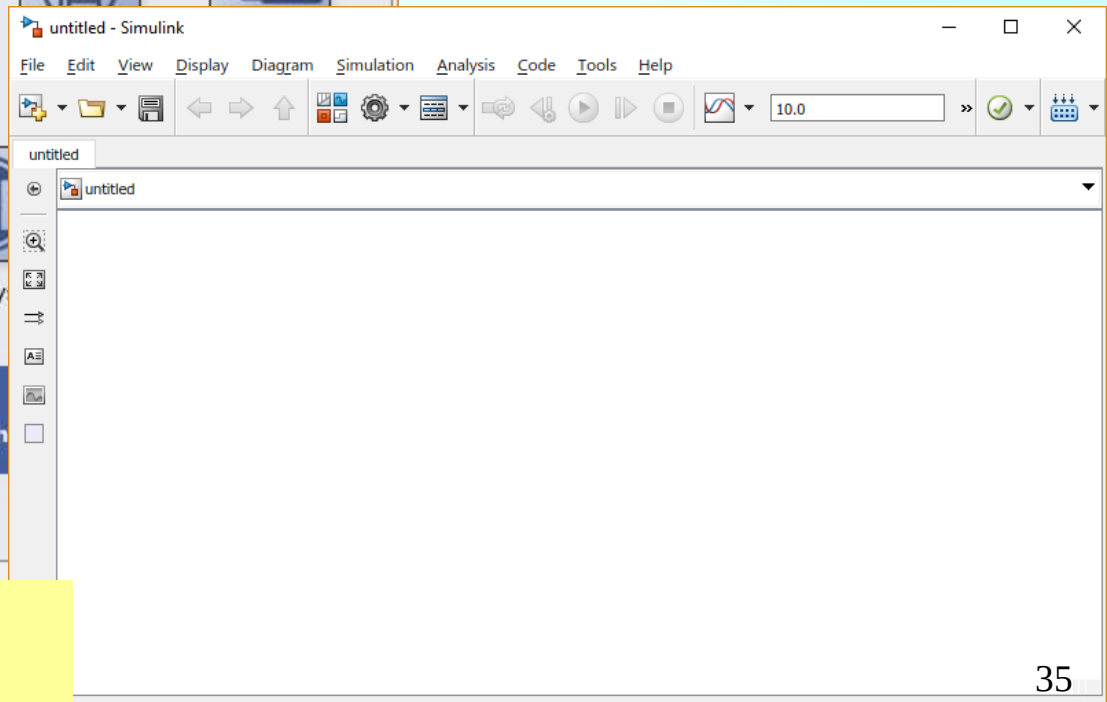
- Симулација линеарних и нелинеатних електричних кола



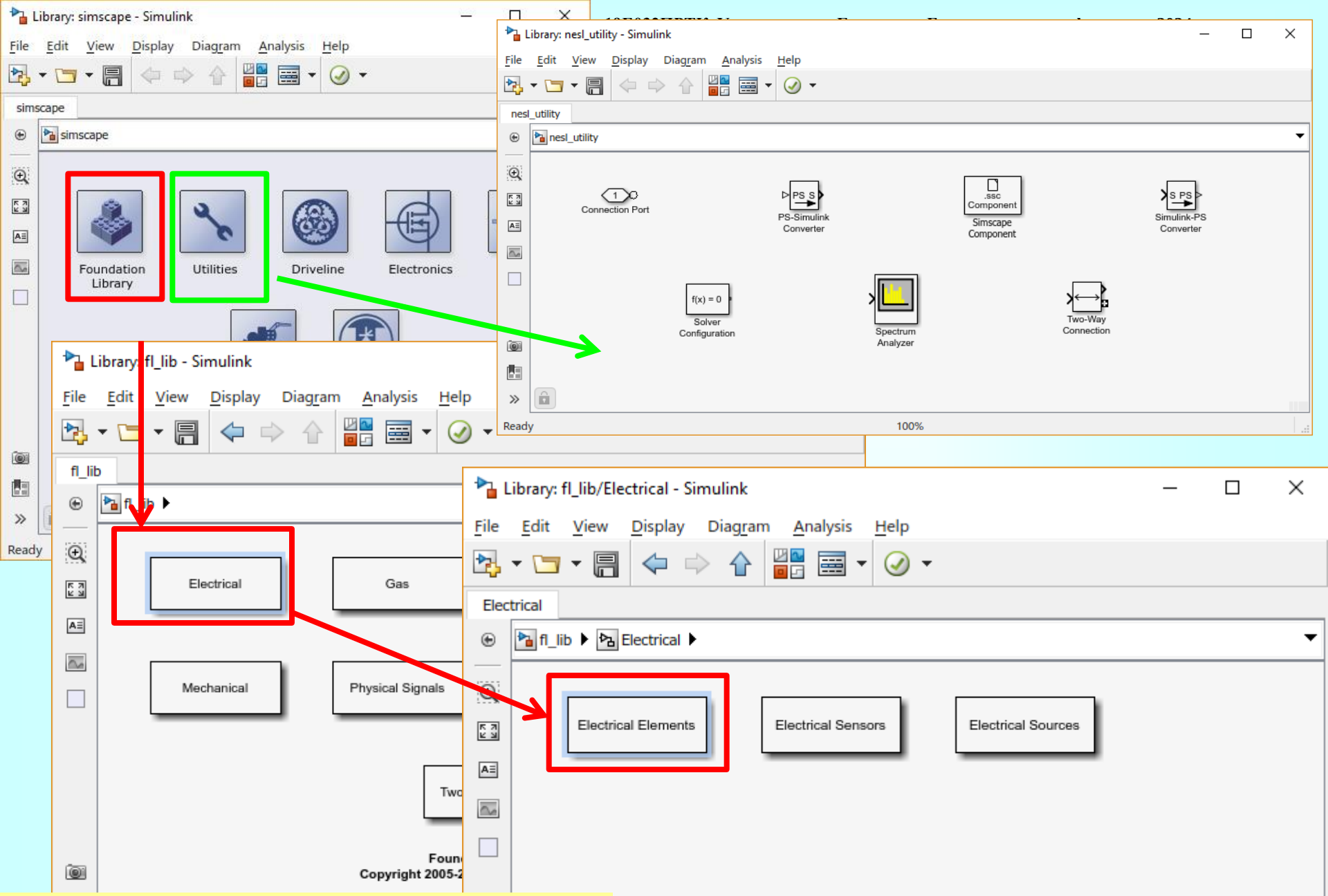

**MATLAB > Simscape > Foundation Library, Utilities**

# Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке



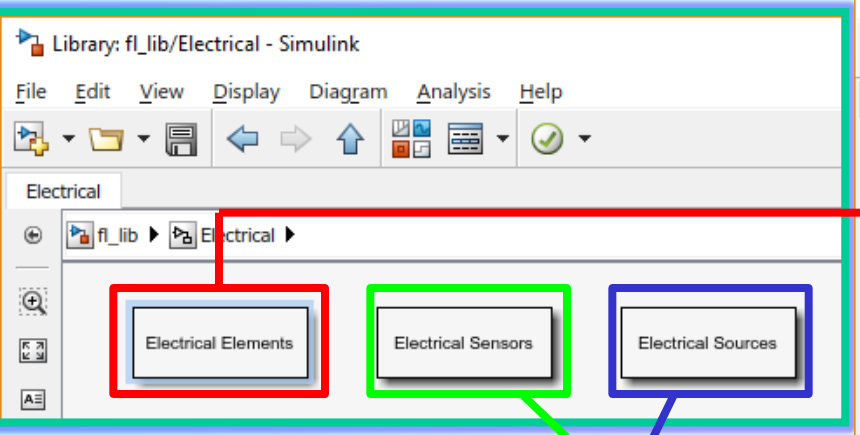



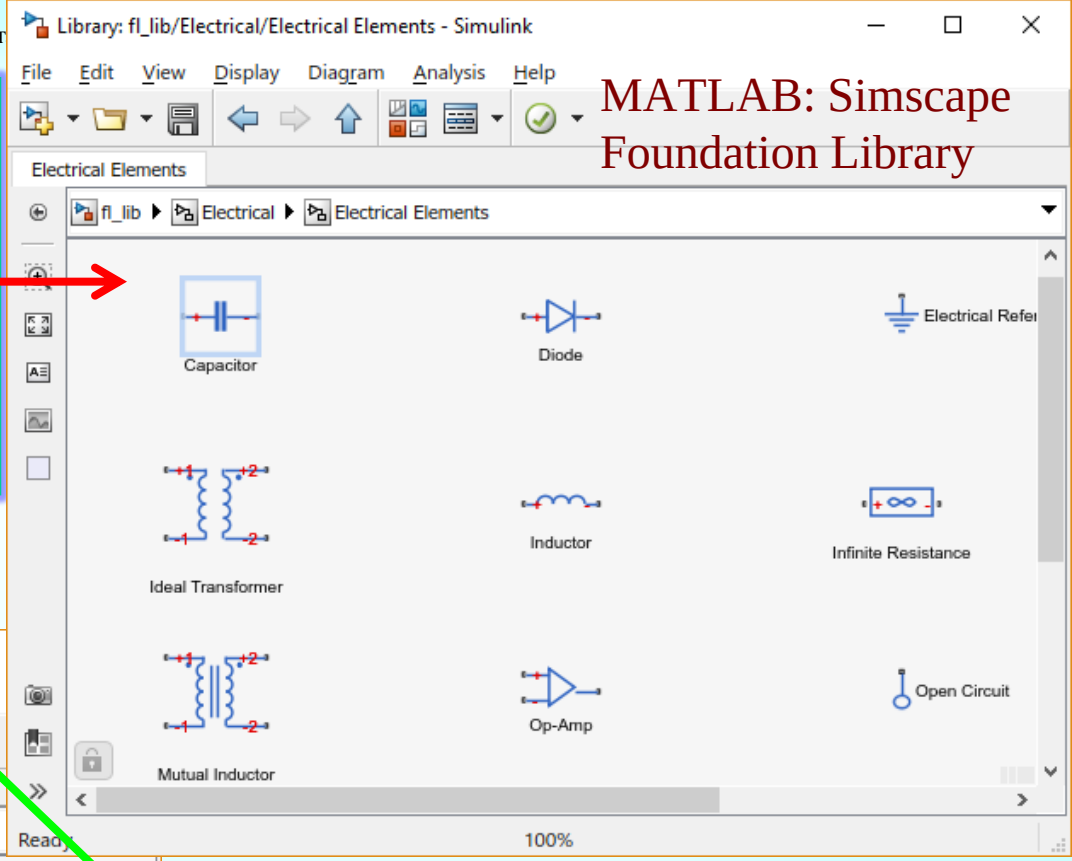

**MATLAB > Simscape > Foundation Library, Utilities**

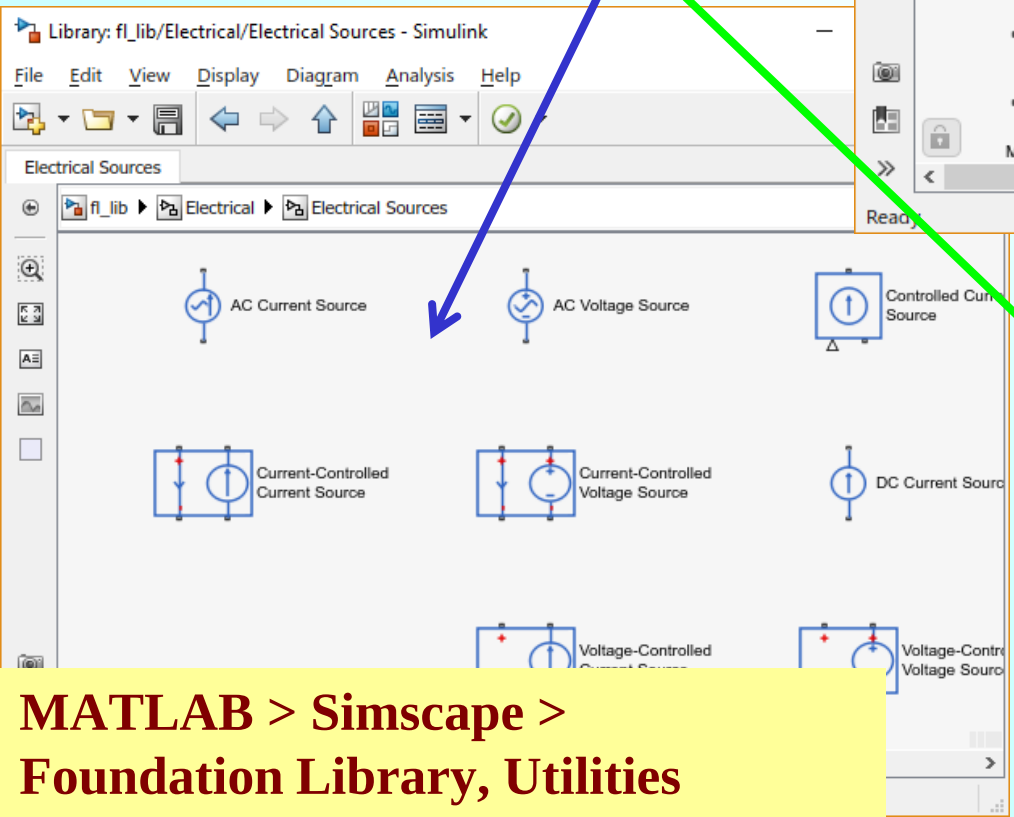


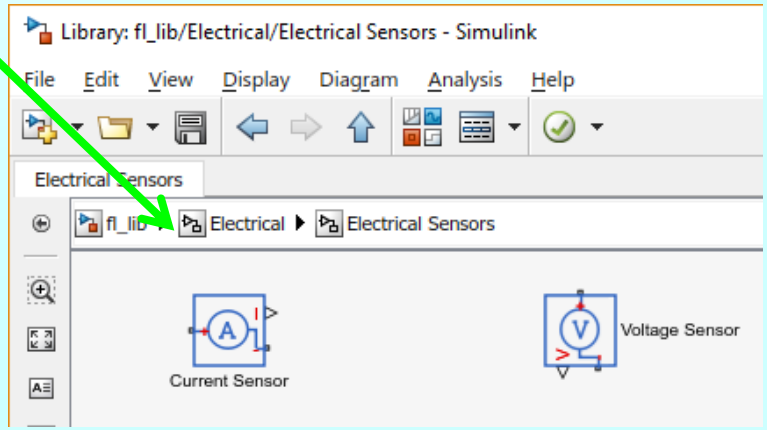

**MATLAB > Simscape > Foundation Library, Utilities**

# MATLAB: Simscape Foundation Library



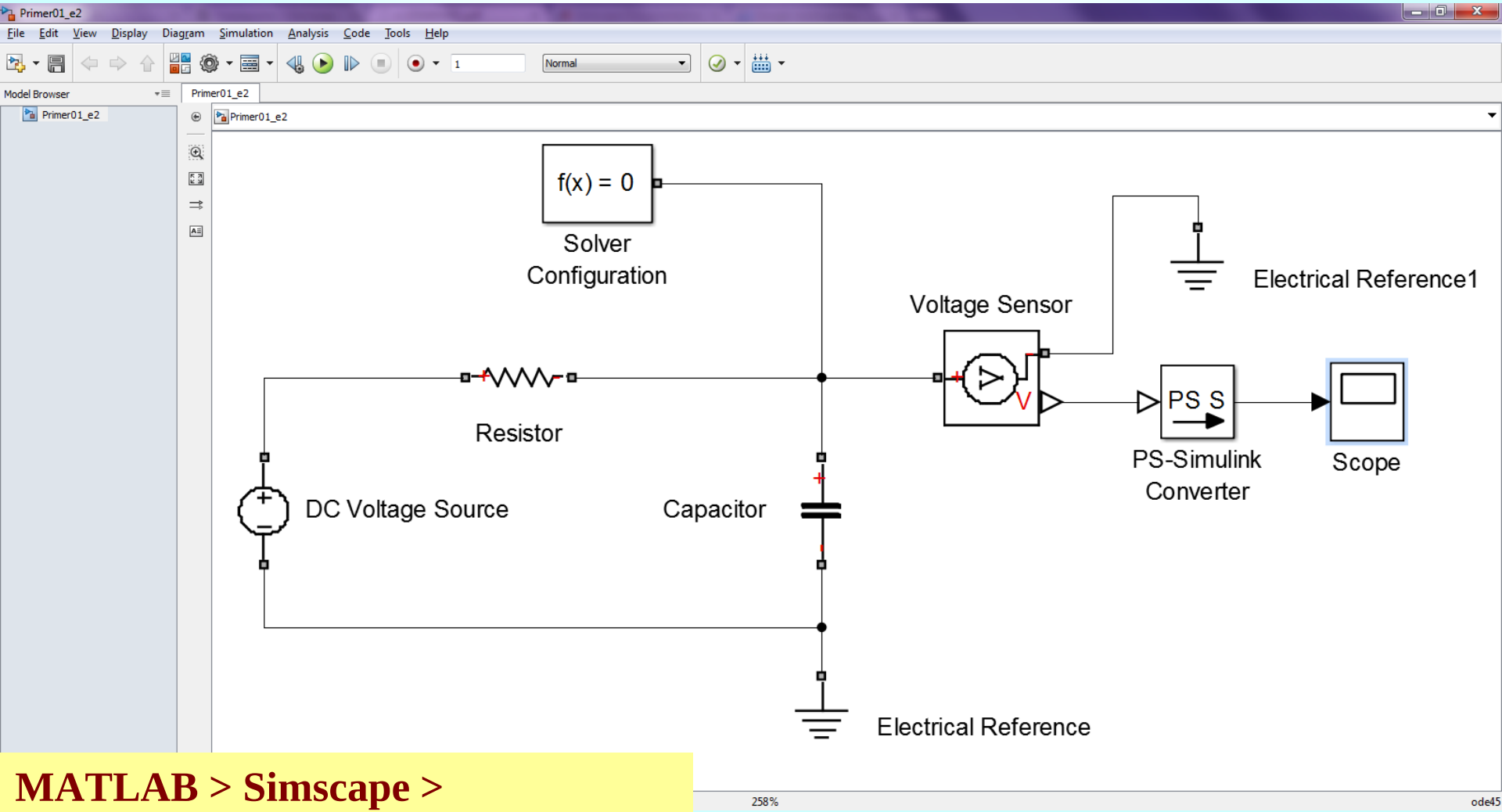



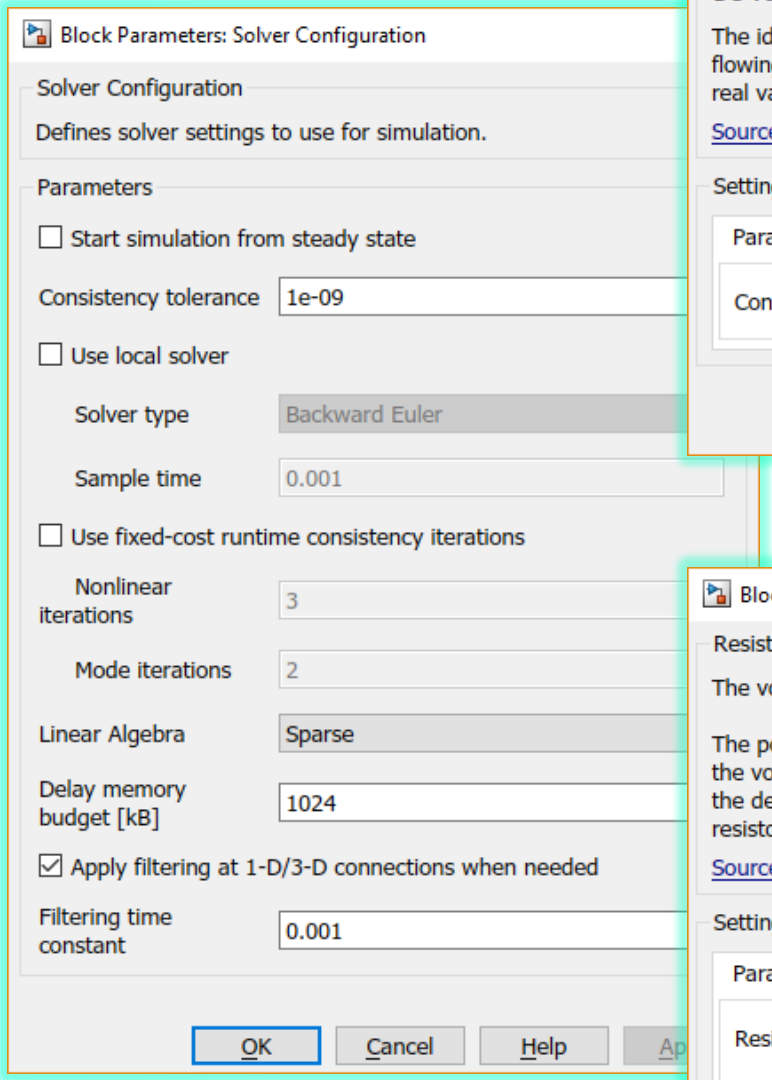



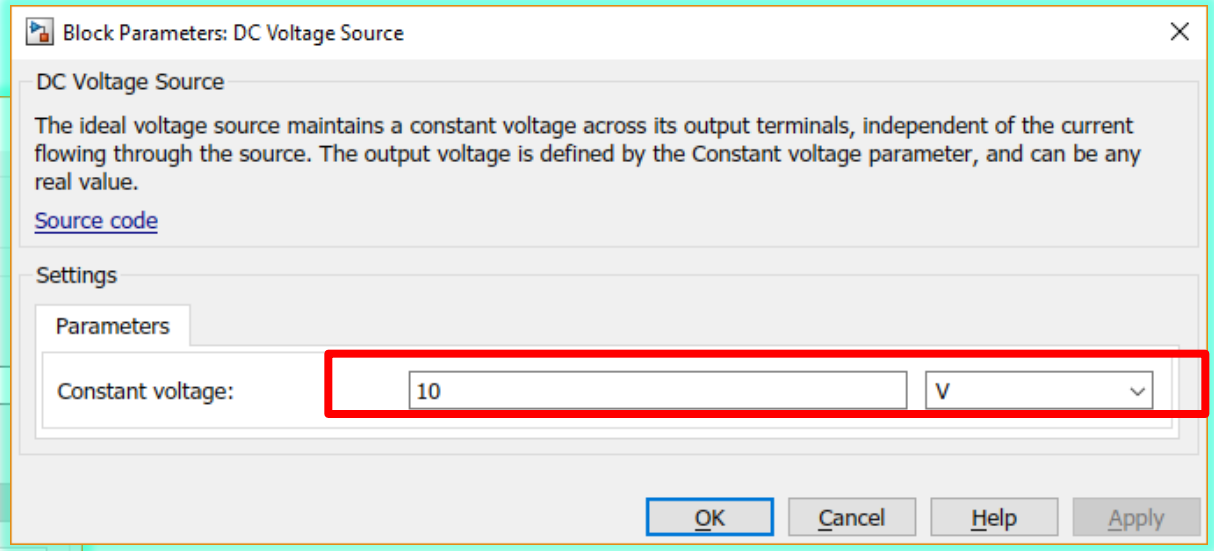

**MATLAB > Simscape > Foundation Library, Utilities**

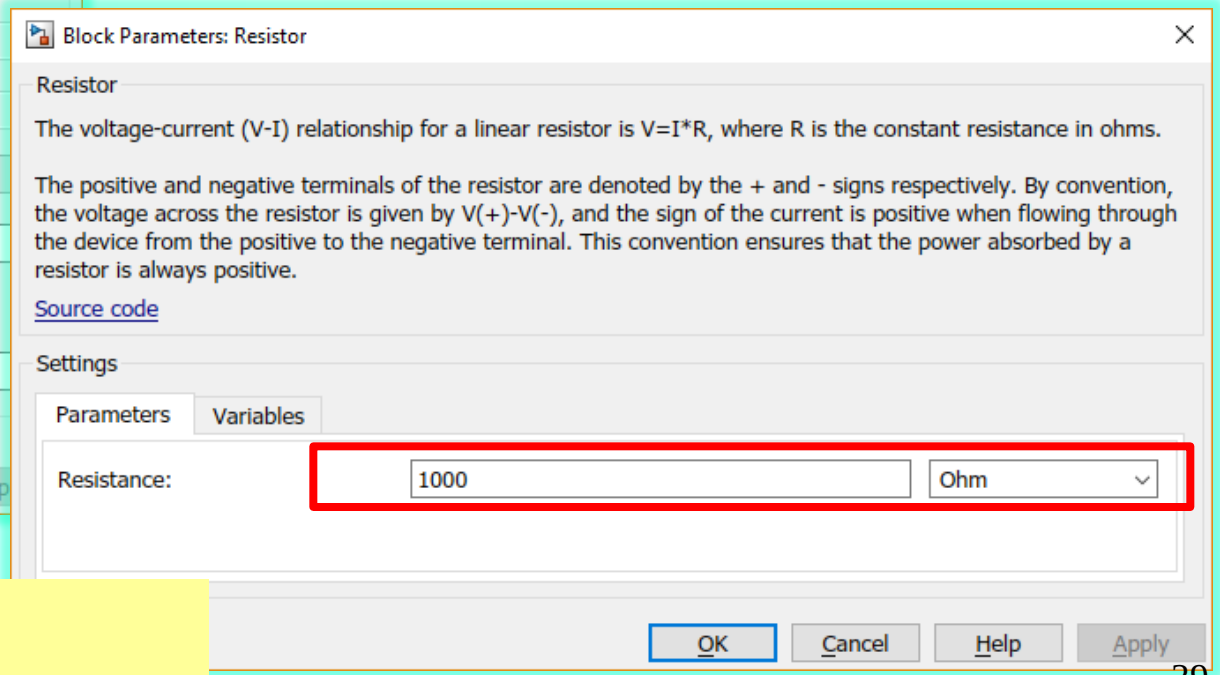
# Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке




**MATLAB > Simscape > Foundation Library, Utilities**




**MATLAB > Simscape > Foundation Library, Utilities**

# Почетни услов...

Block Parameters: Capacitor

Capacitor

Models a linear capacitor. The relationship between voltage V and and current I is I=C*dV/dt where C is the capacitance in farads.

The Series resistance and Parallel conductance represent small parasitic effects. The parallel conductance can be used to model dielectric losses and the series resistance used to represent the effective series resistance (ESR) of the capacitor. Simulation of some circuits may require the presence of the small series resistance. Consult the documentation for further details.

Source code

Settings

Parameters | Variables

| | | |
|---|---|---|
| Capacitance: | 1e-6 | F |
| Series resistance: | 0 | Ohm |
| Parallel conductance: | 0 | 1/Ohm |

OK | Cancel | Help | Apply

*dV/dt where C is the capacitance in farads.

arallel conductance can be used to model
nce (ESR) of the capacitor. Simulation of
mentation for further details.

Settings

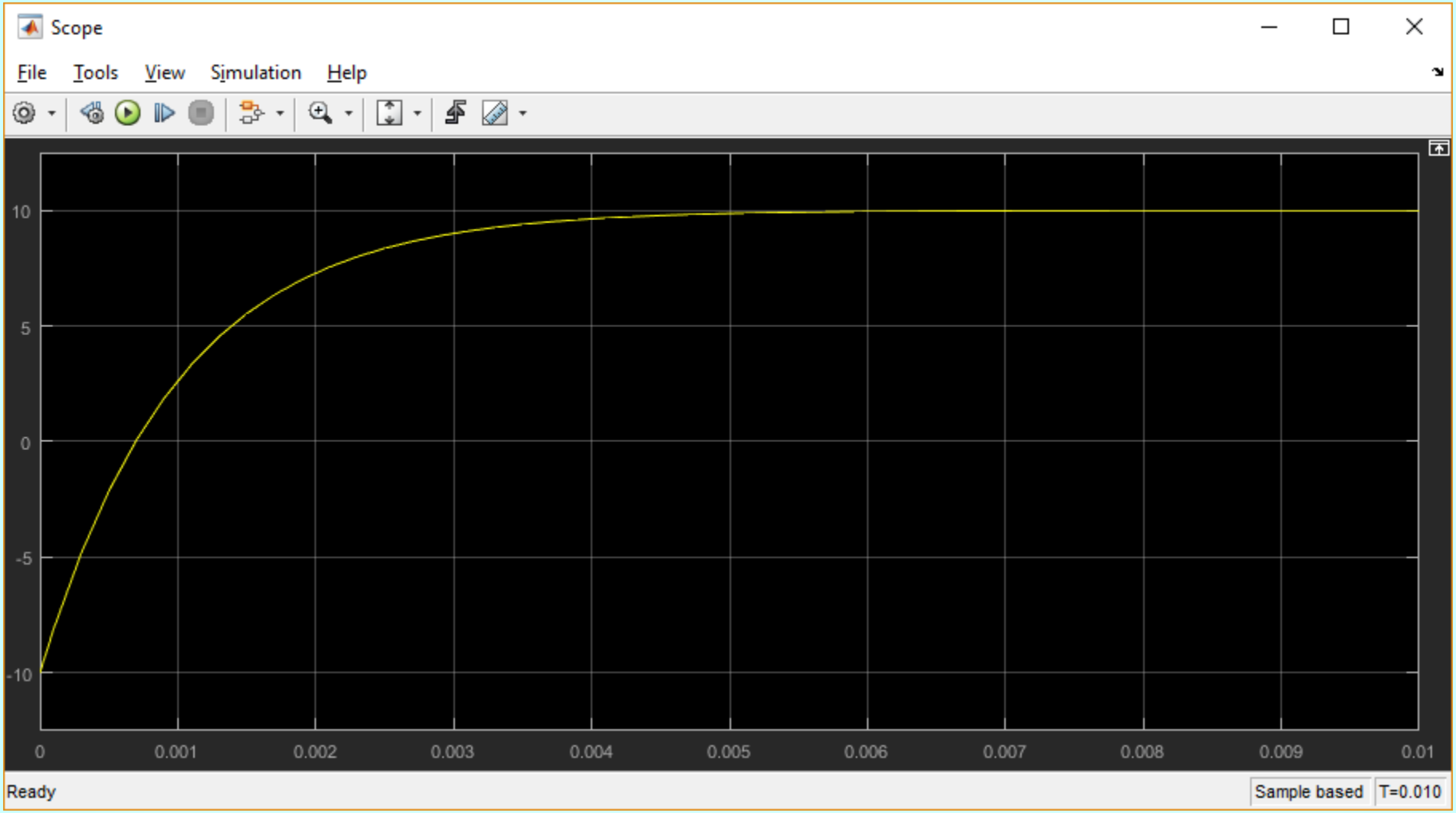
Parameters | Variables

| Override | Variable | Priority | Beginning Value | Unit |
|---|---|---|---|---|
| ☐ | Current | None | 0 | A |
| ☐ | Voltage | None | 0 | V |
| ☑ | Capacitor voltage | High | -10 | V |

OK | Cancel | Help | Apply

**MATLAB > Simscape > Foundation Library, Utilities**

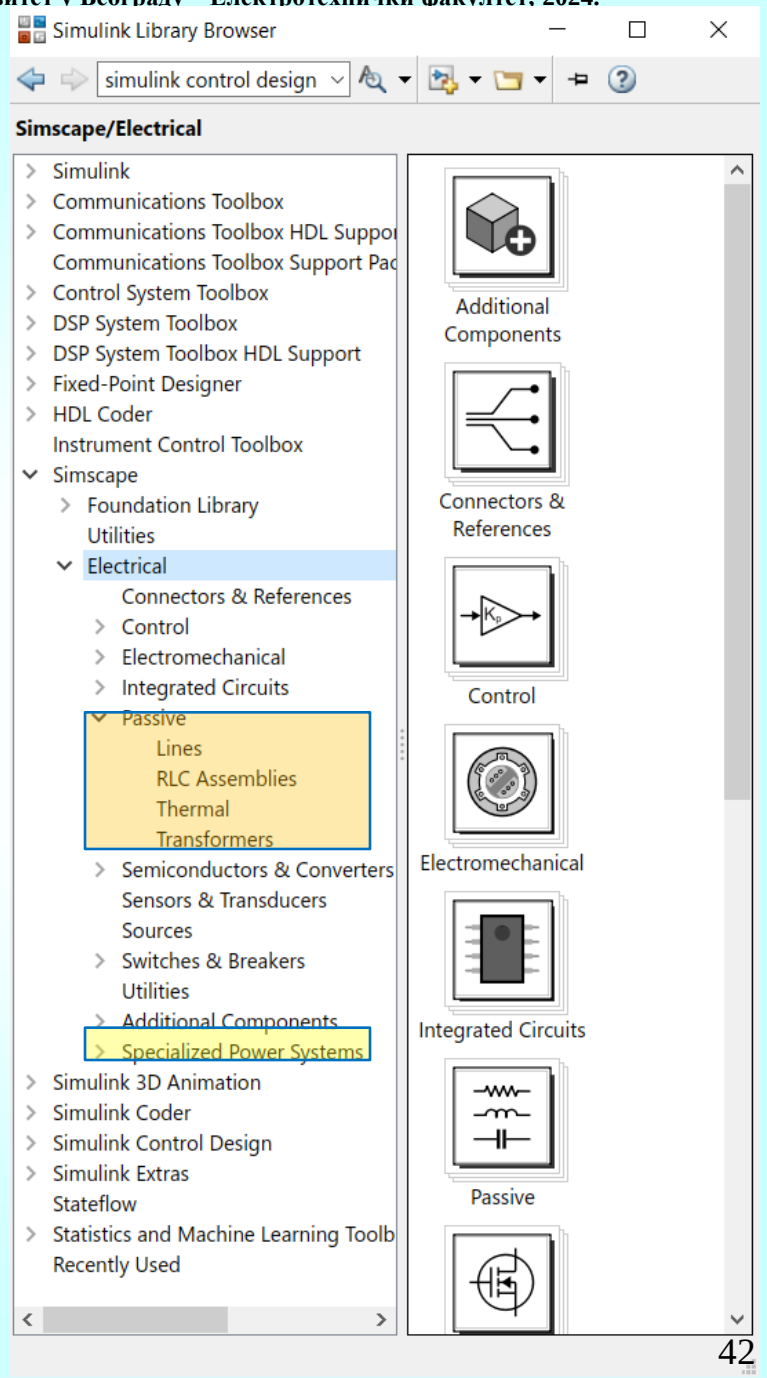
# Одређивање одзива...




**MATLAB > Simscape > Foundation Library, Utilities**

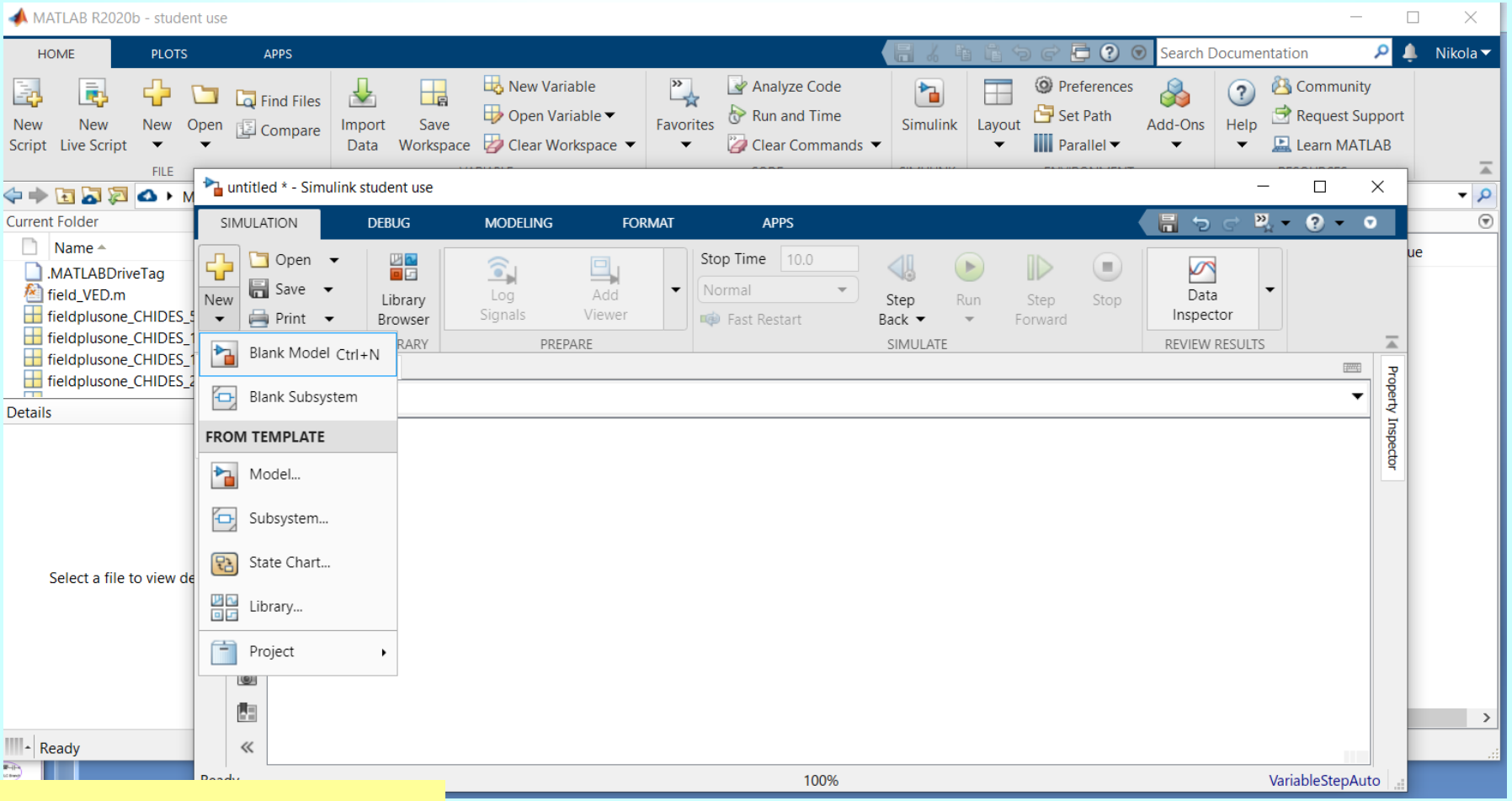
# Simulink > Simscape > Electrical

- Библиотека за симулацију и нумеричку анализу електроенергетских система
- Трофазни извори, водови, трансформатори, потрошачи
- Термална анализа



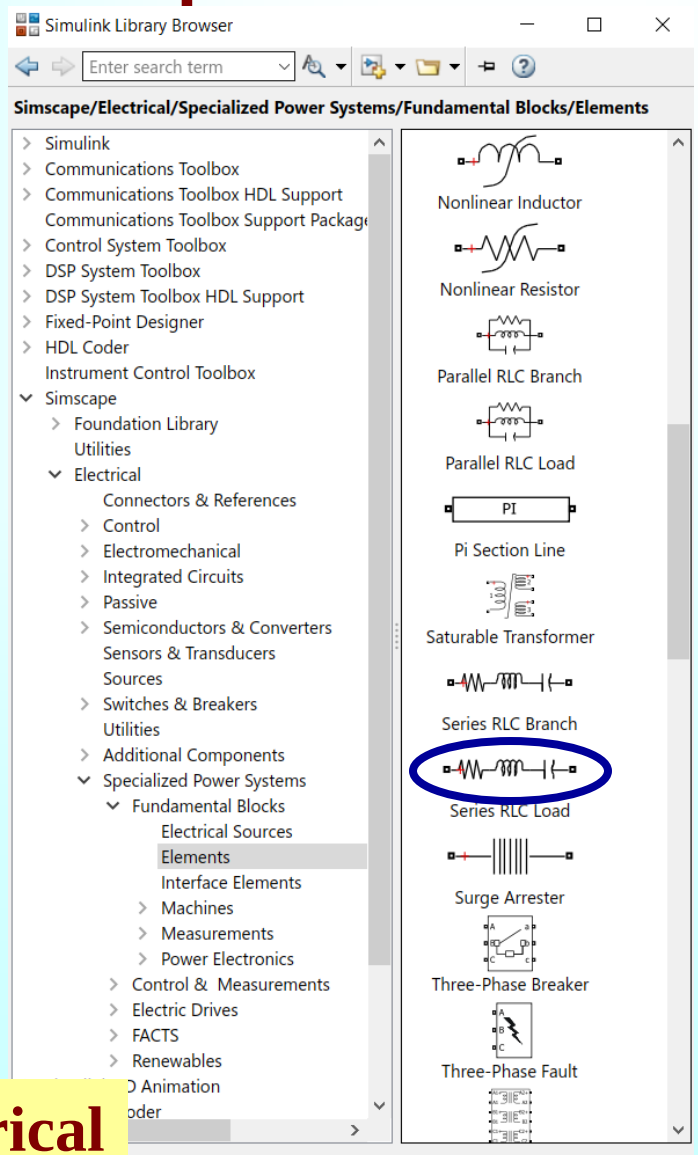

**Simscape > Electrical**

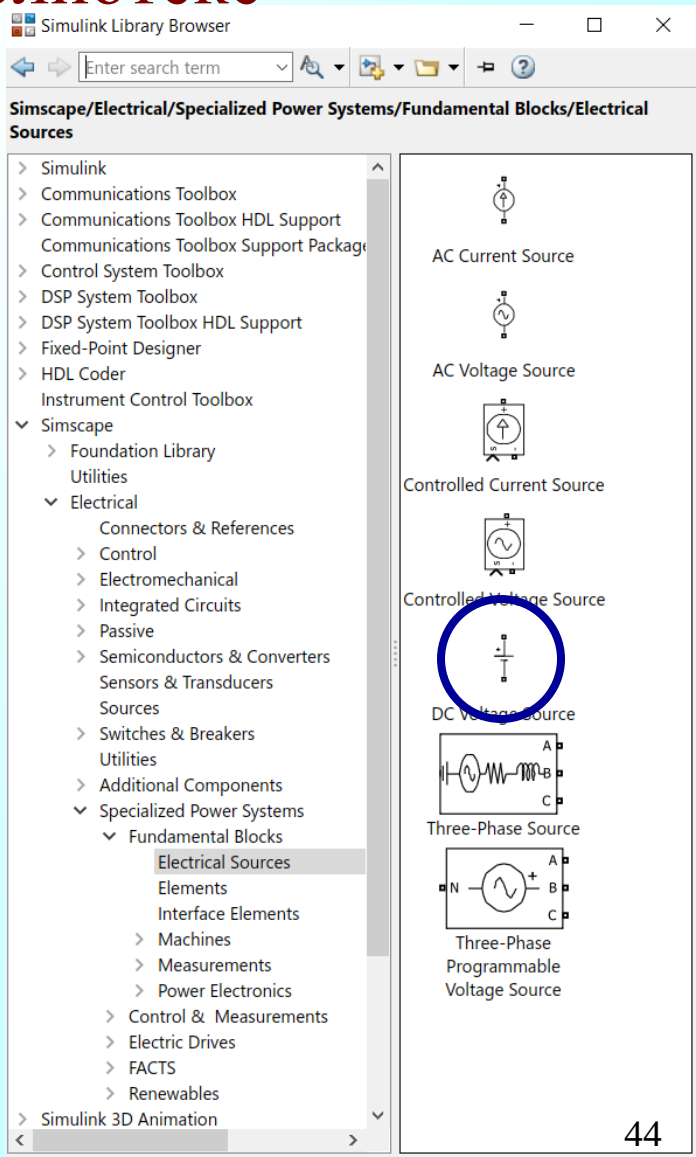
# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке




**Simscape > Electrical**

# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

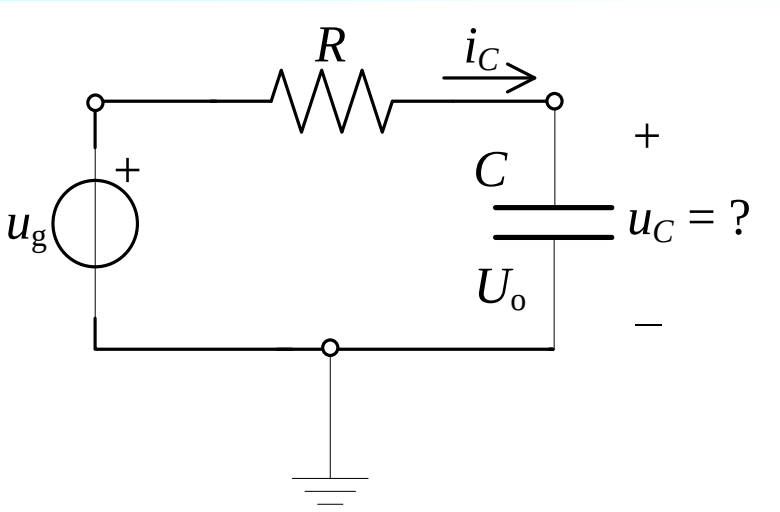


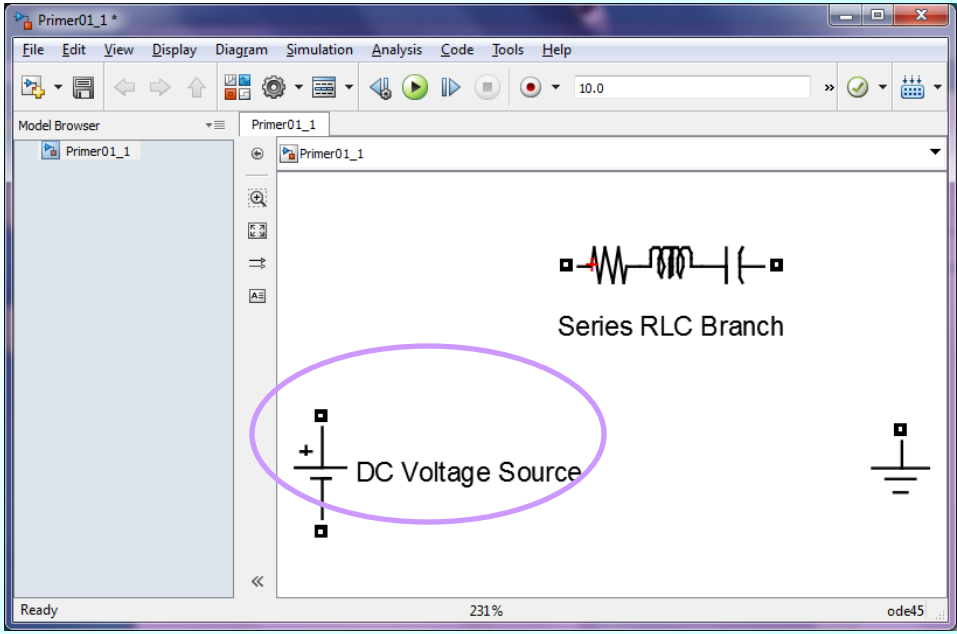




**Simscape > Electrical**

# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

коло је образовано у тренутку $t_0 = 0$



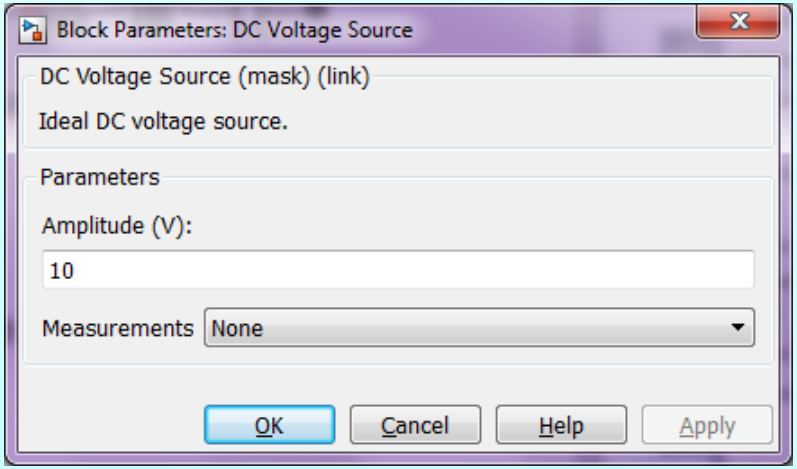




$R = 1\,\mathrm{k\Omega}$

$C = 1\,\mu\mathrm{F}$

$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$

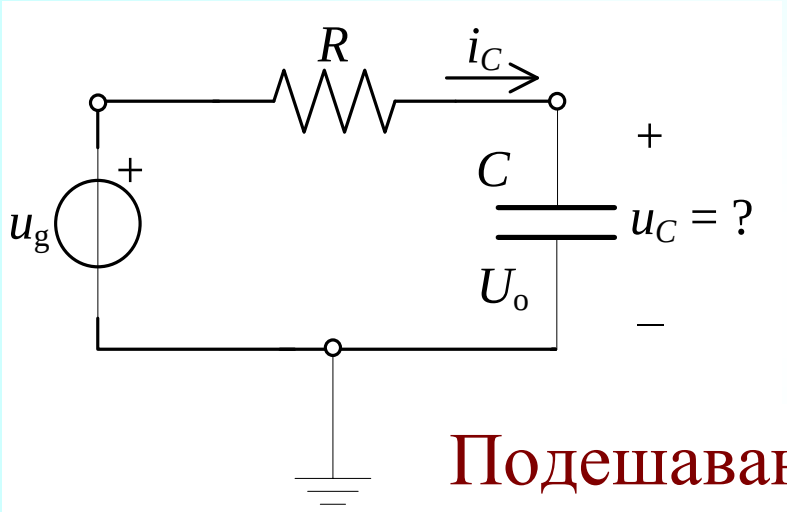
$u(t_0^-) = U_0 = -10\,\mathrm{V}$




**Simscape > Electrical**

# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

коло је образовано у тренутку $t_0 = 0$



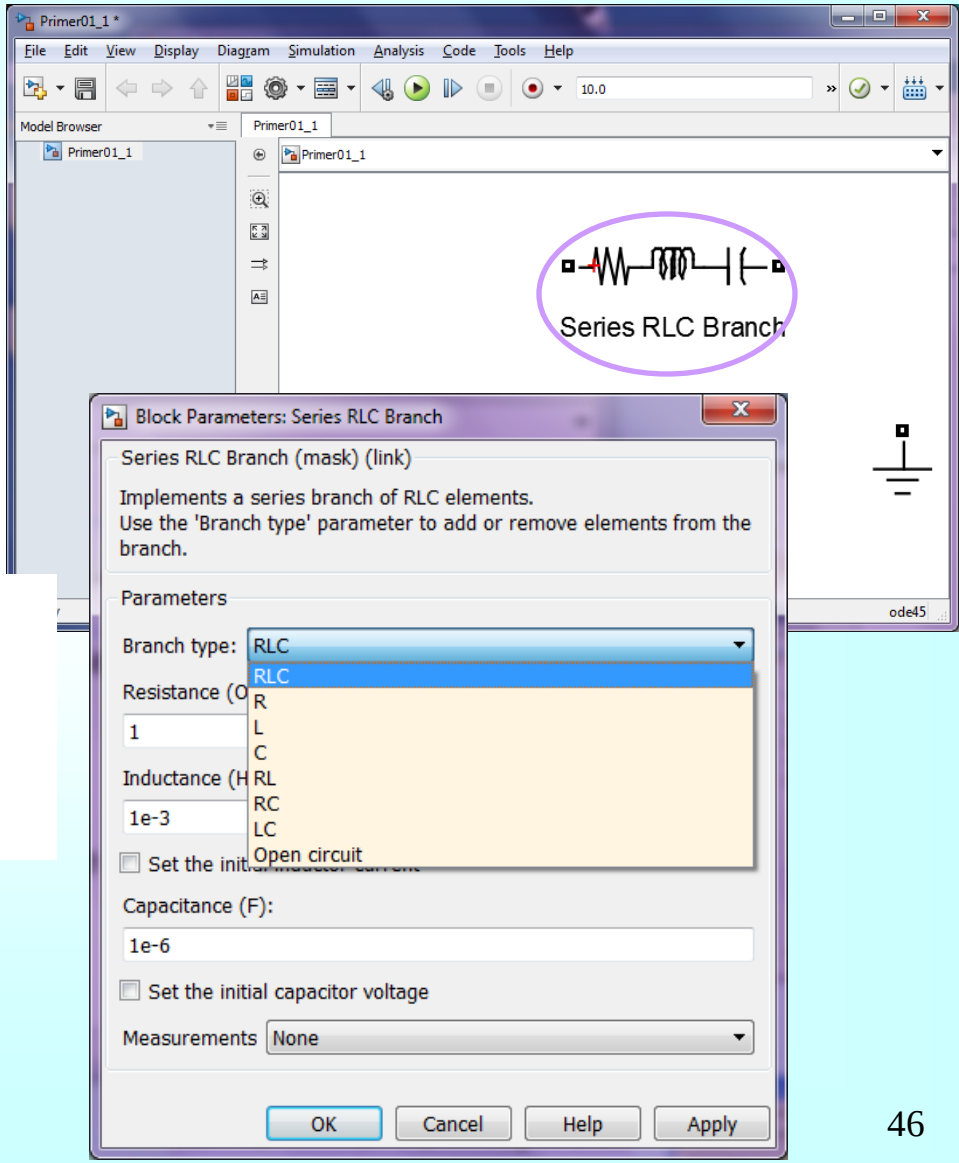

$R = 1\,\mathrm{k\Omega}$

$C = 1\,\mu\mathrm{F}$

$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$

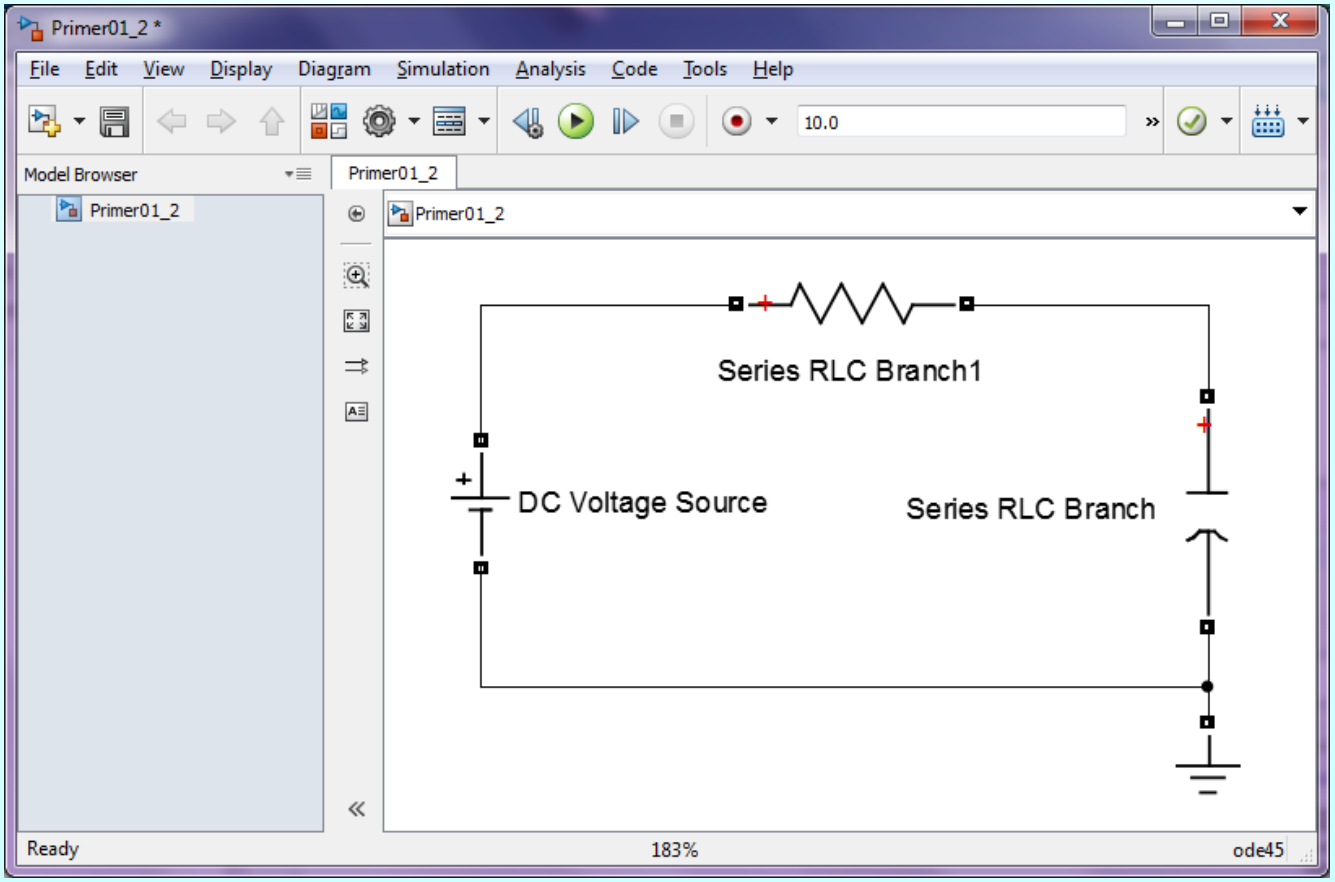
$u(t_0^-) = U_0 = -10\,\mathrm{V}$

## Подешавање параметара симулације




**Simscape > Electrical**

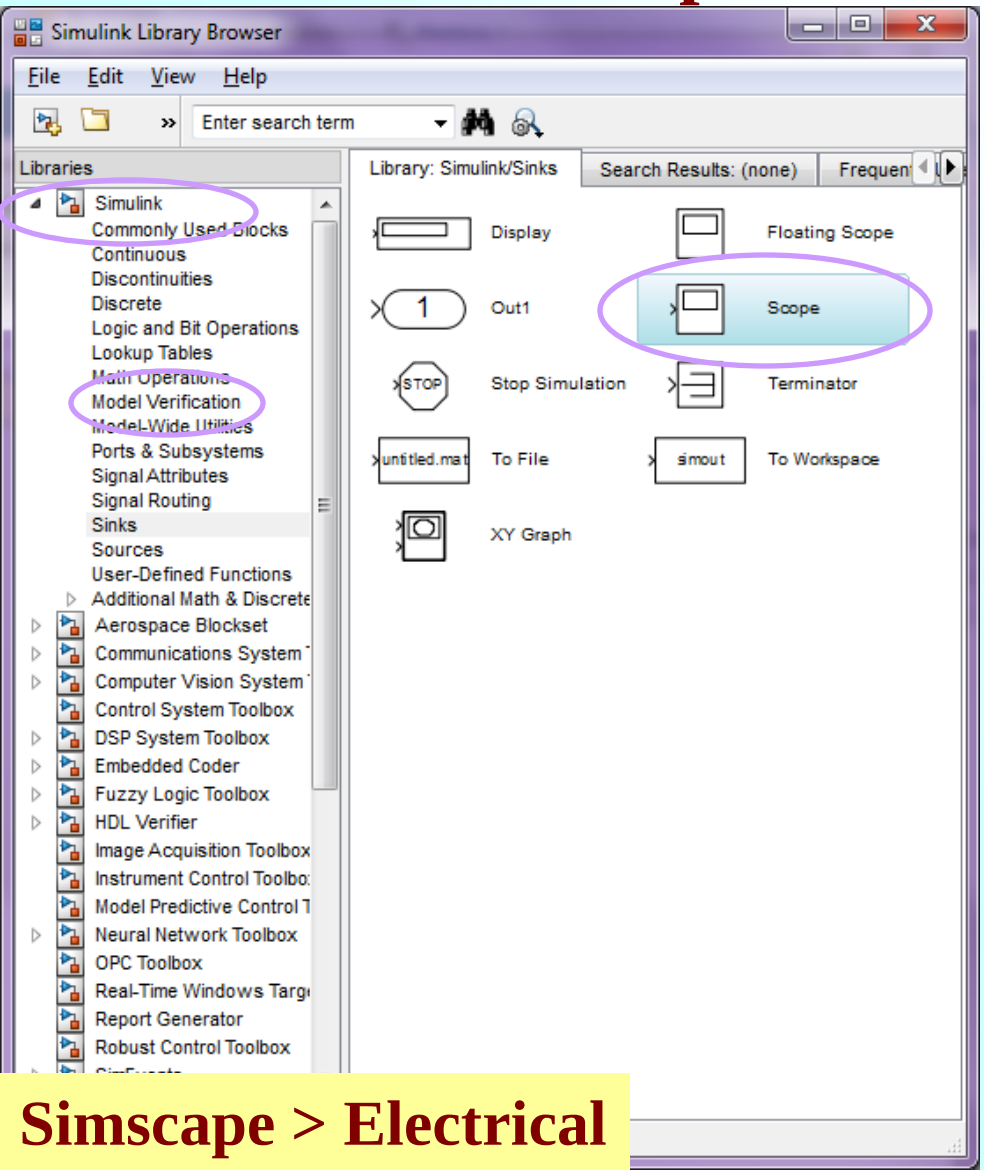
# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

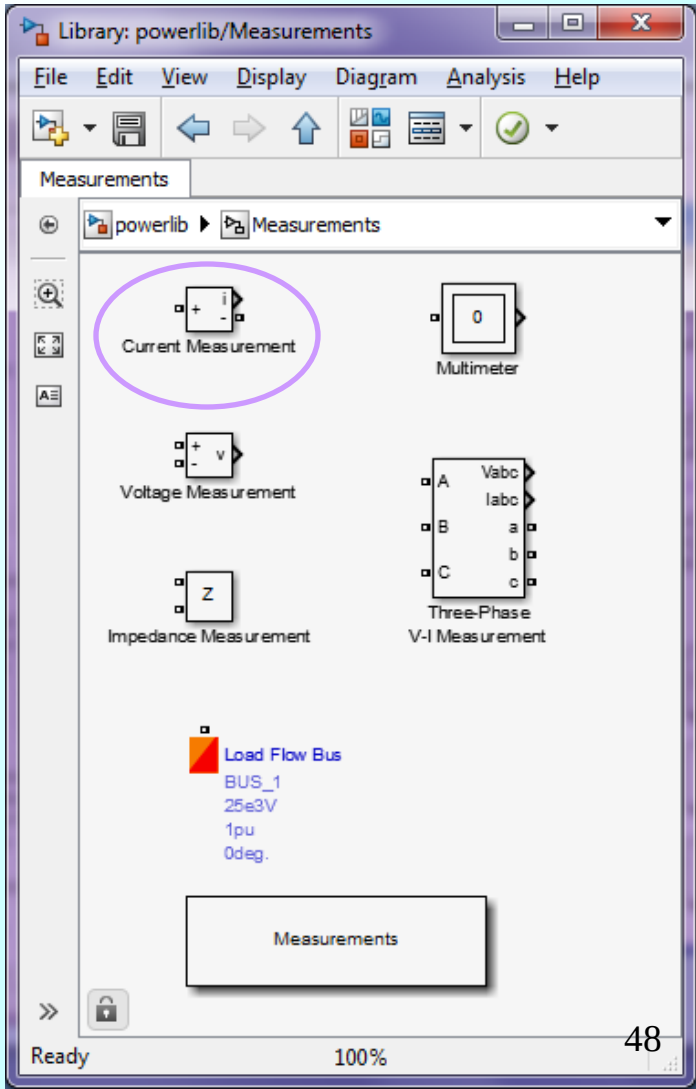



**Како се мери напон?**

**Simscape > Electrical**

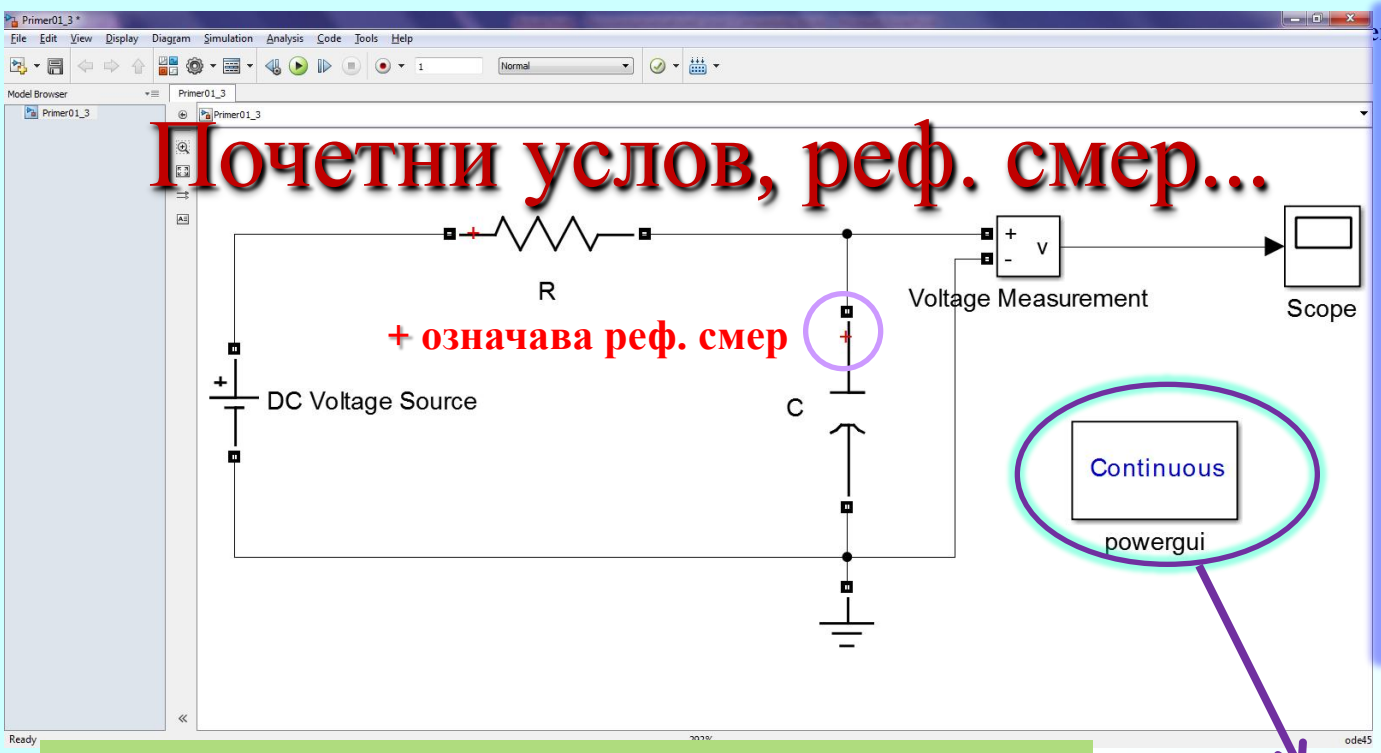
# Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке



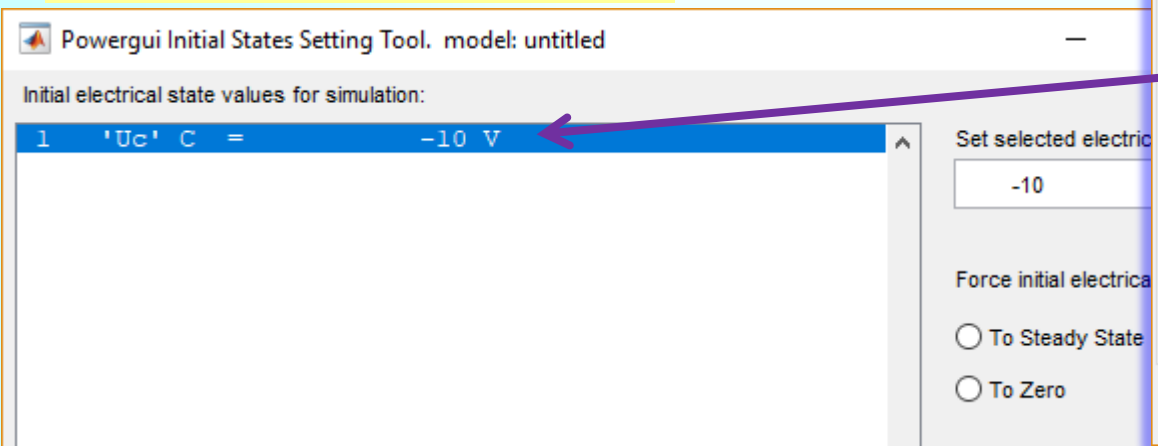

**Simscape > Electrical**

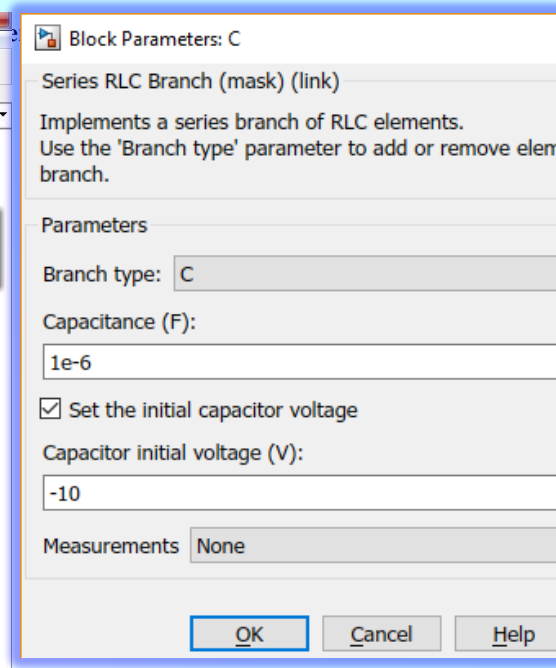
# Почетни услов, реф. смер...

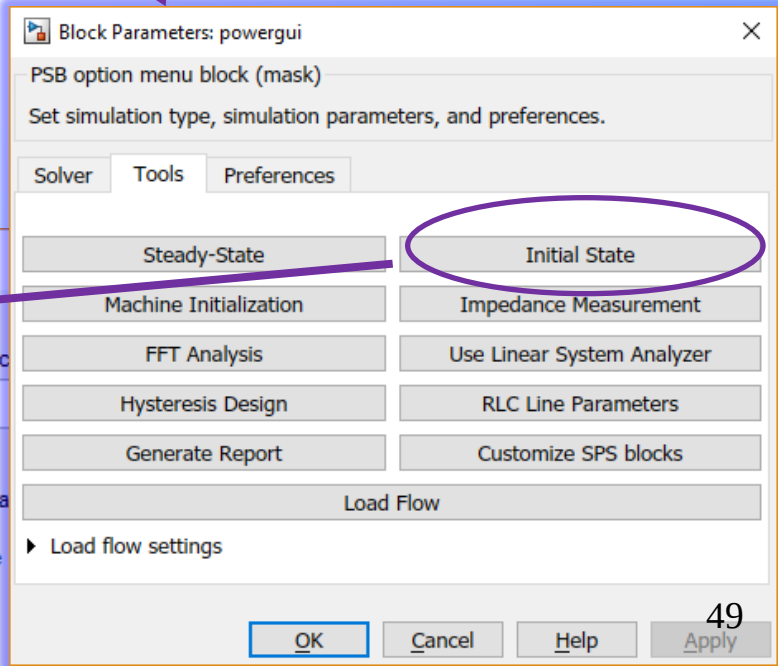


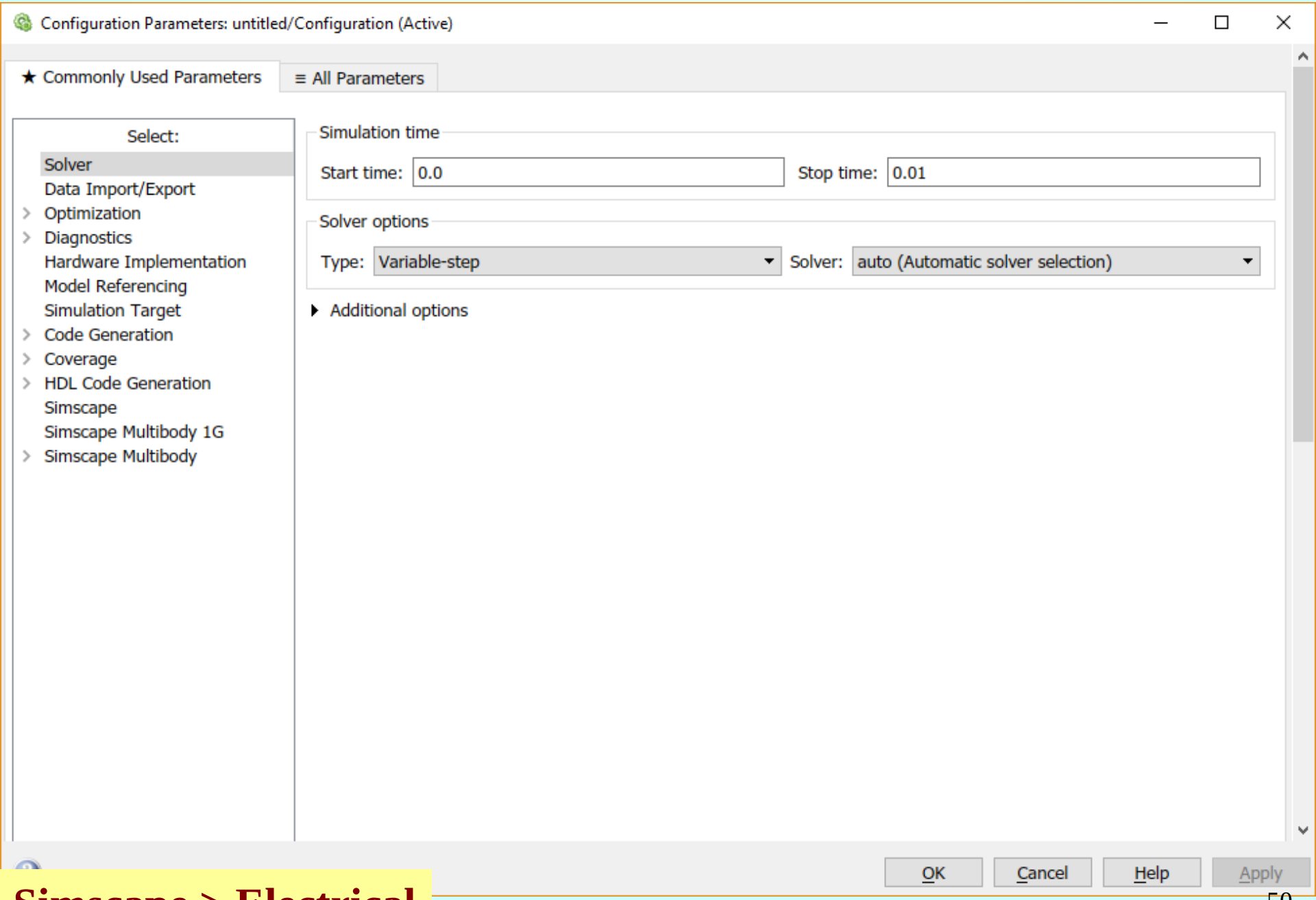

**Плоче кондезатора се разликују!!!**

**Simscape > Electrical**

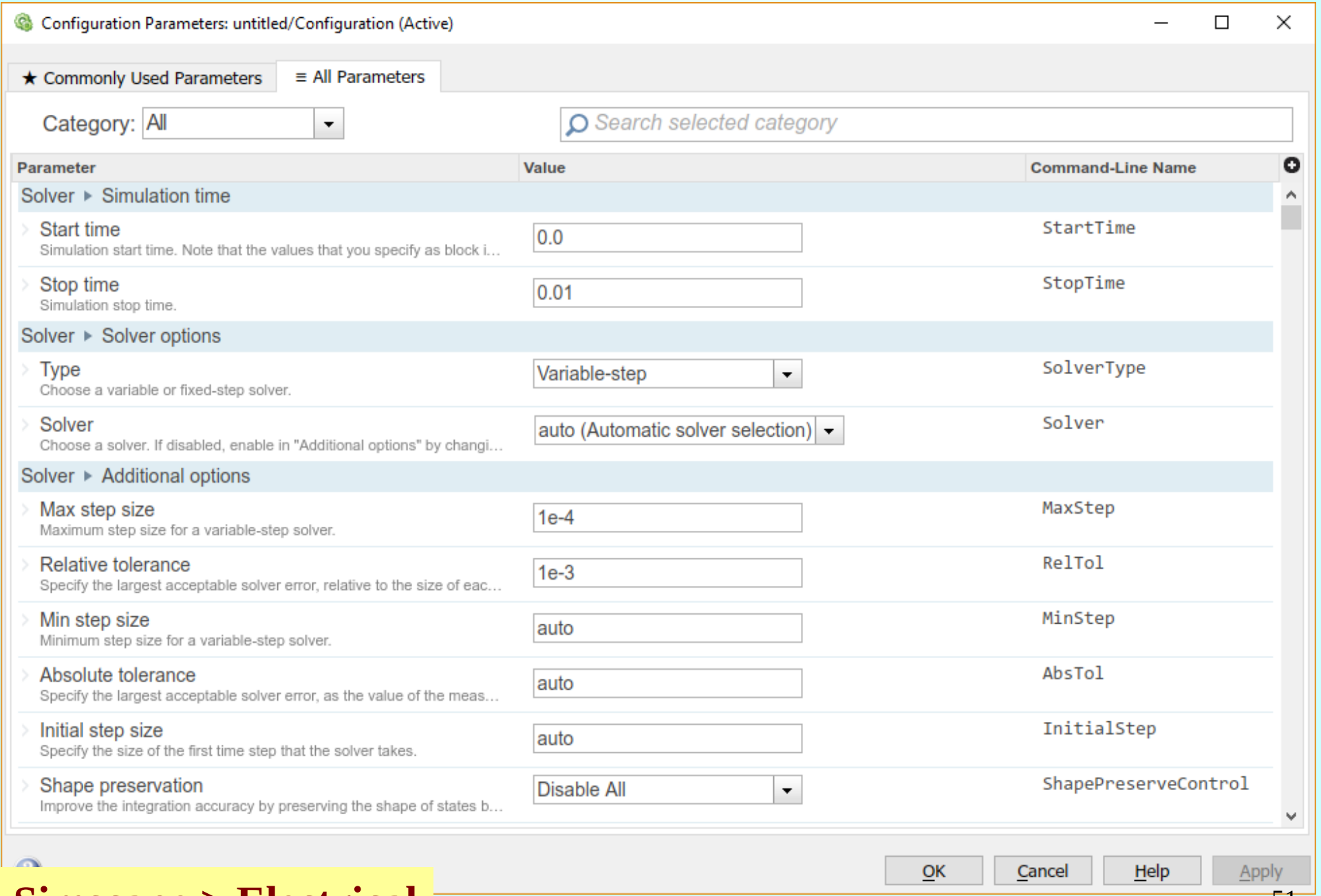


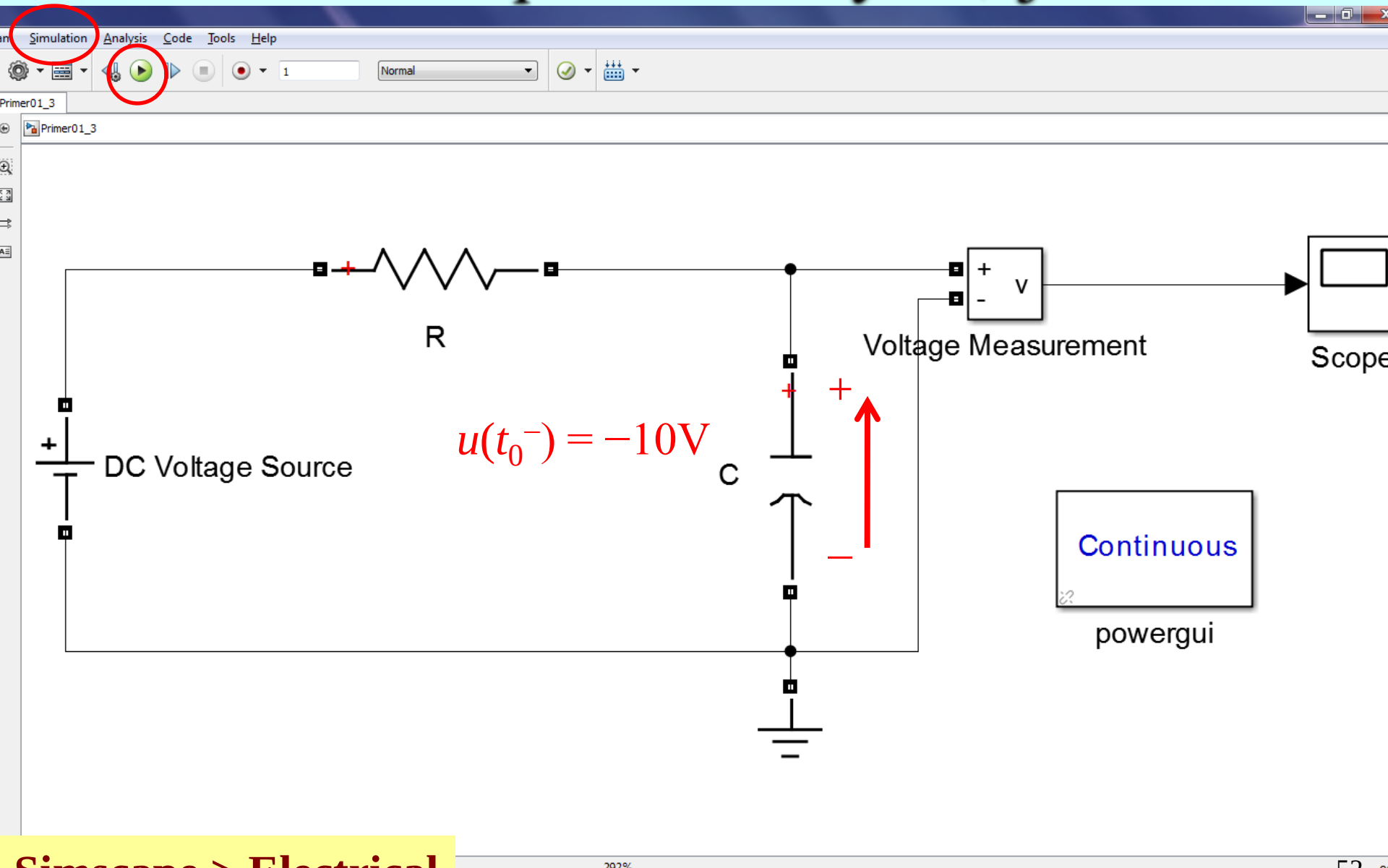



**Simscape > Electrical**



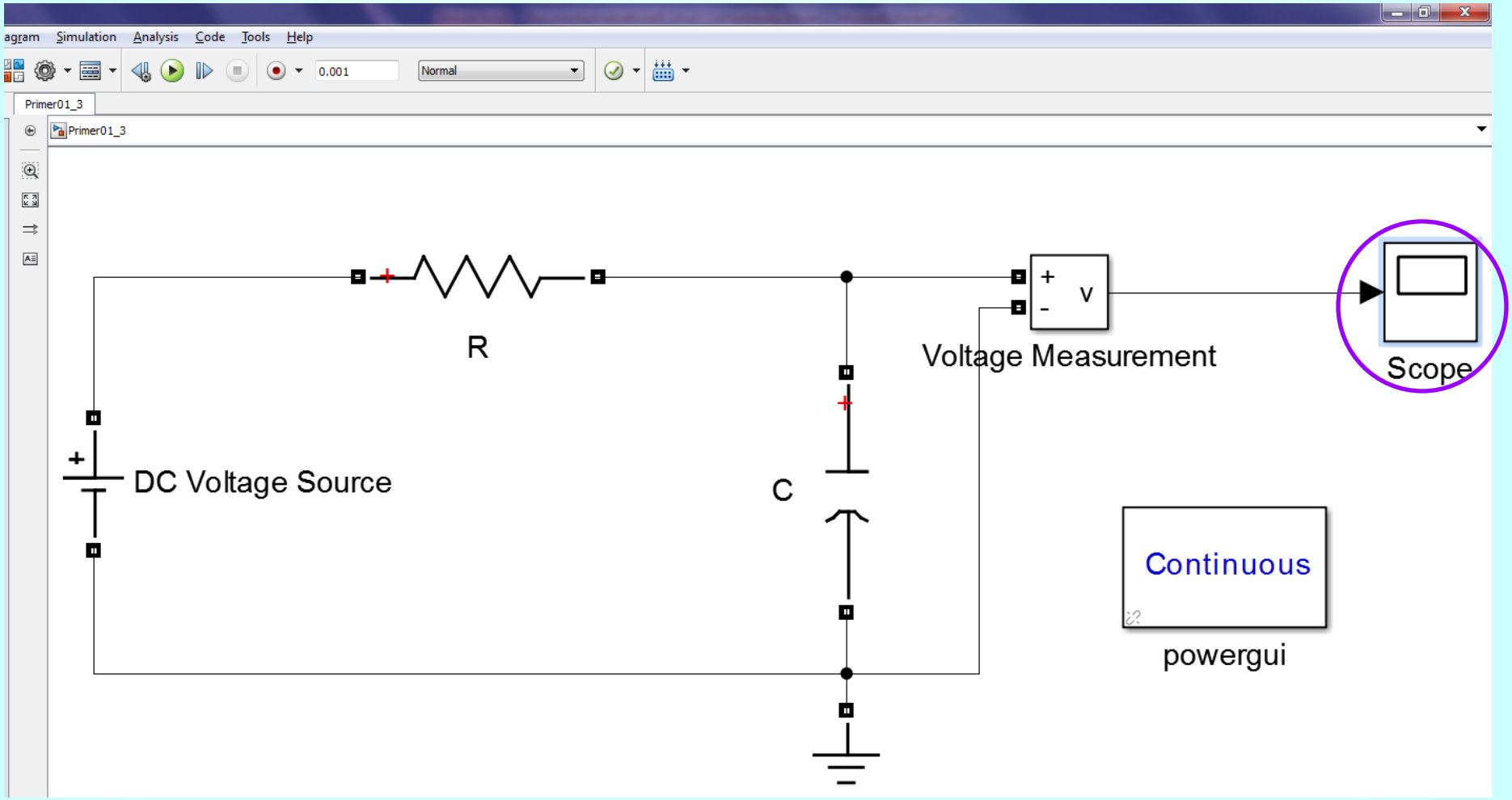

**Simscape > Electrical**

# Покретање симулације...

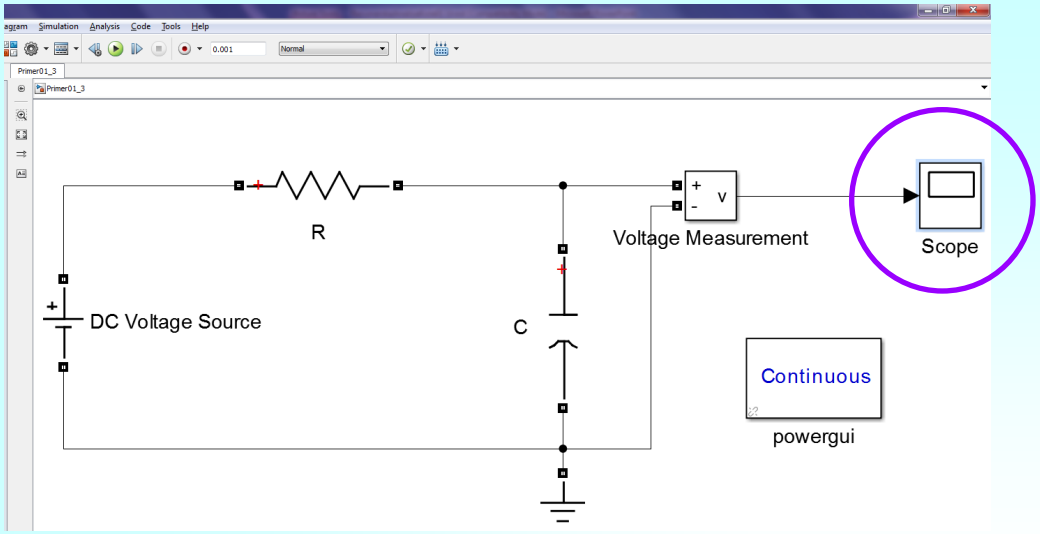


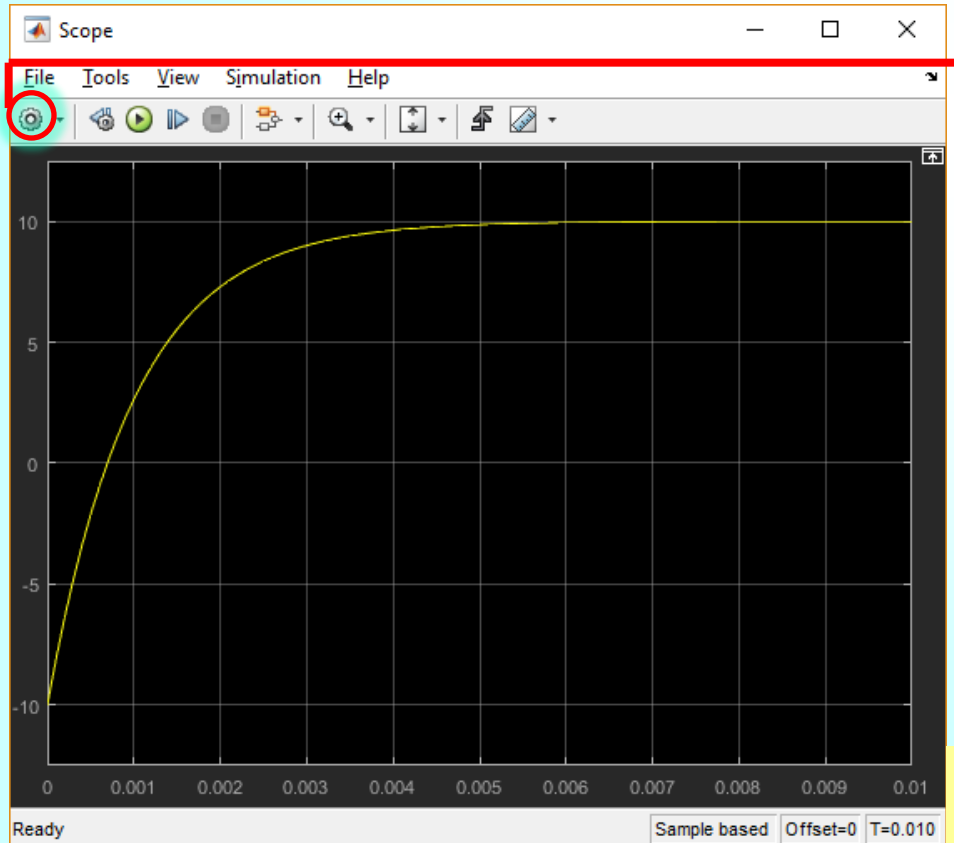

**Simscape > Electrical**

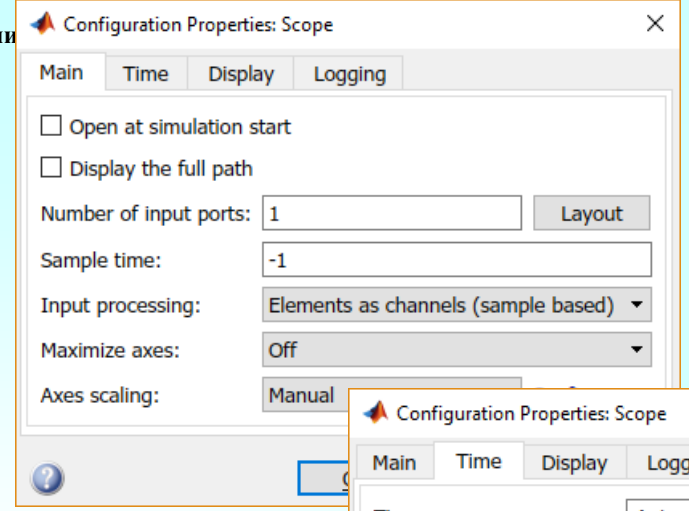
# Налажење одзива... Осцилоскоп

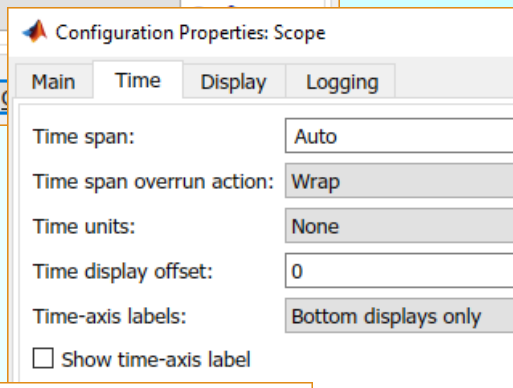


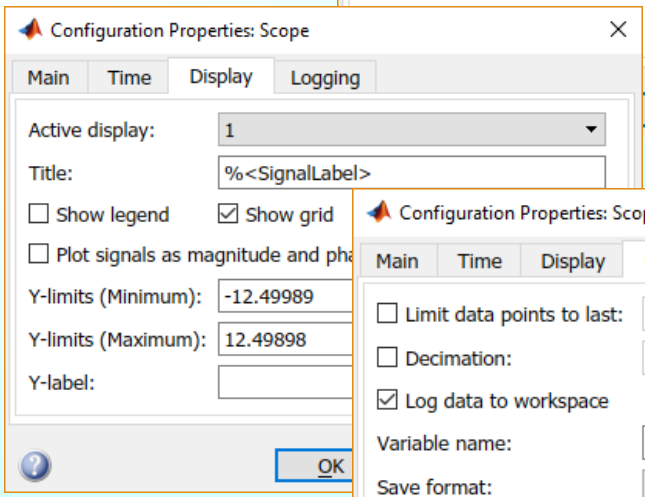

**Simscape > Electrical**

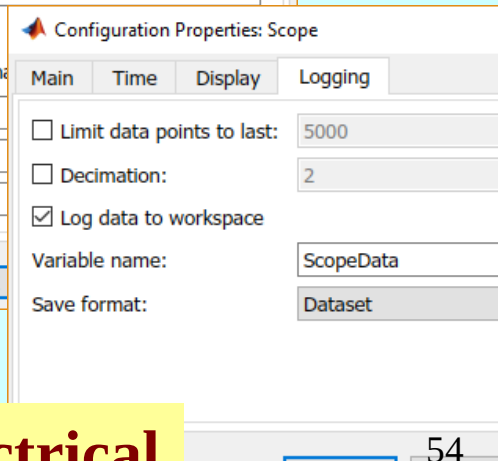


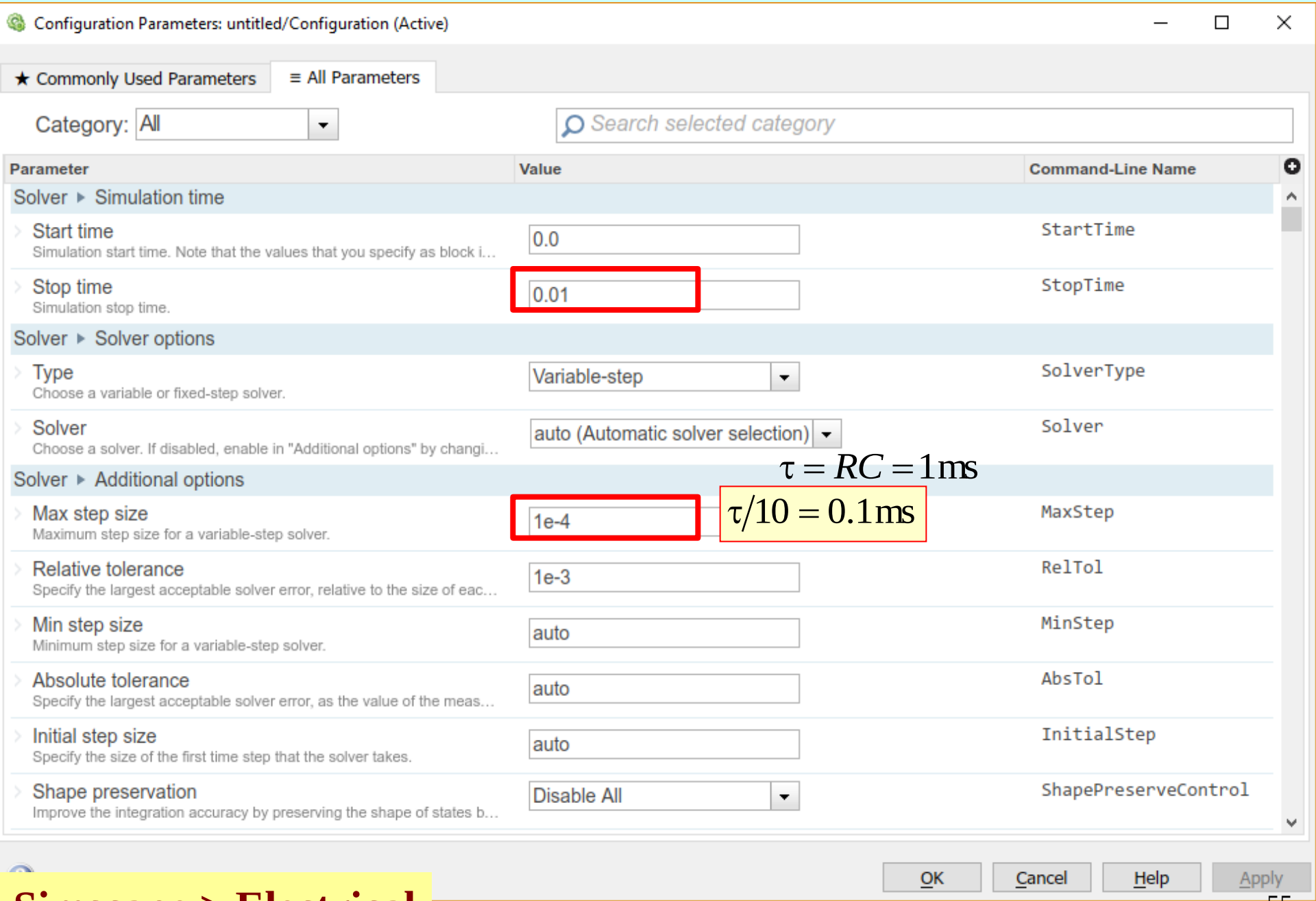




**Simscape > Electrical**



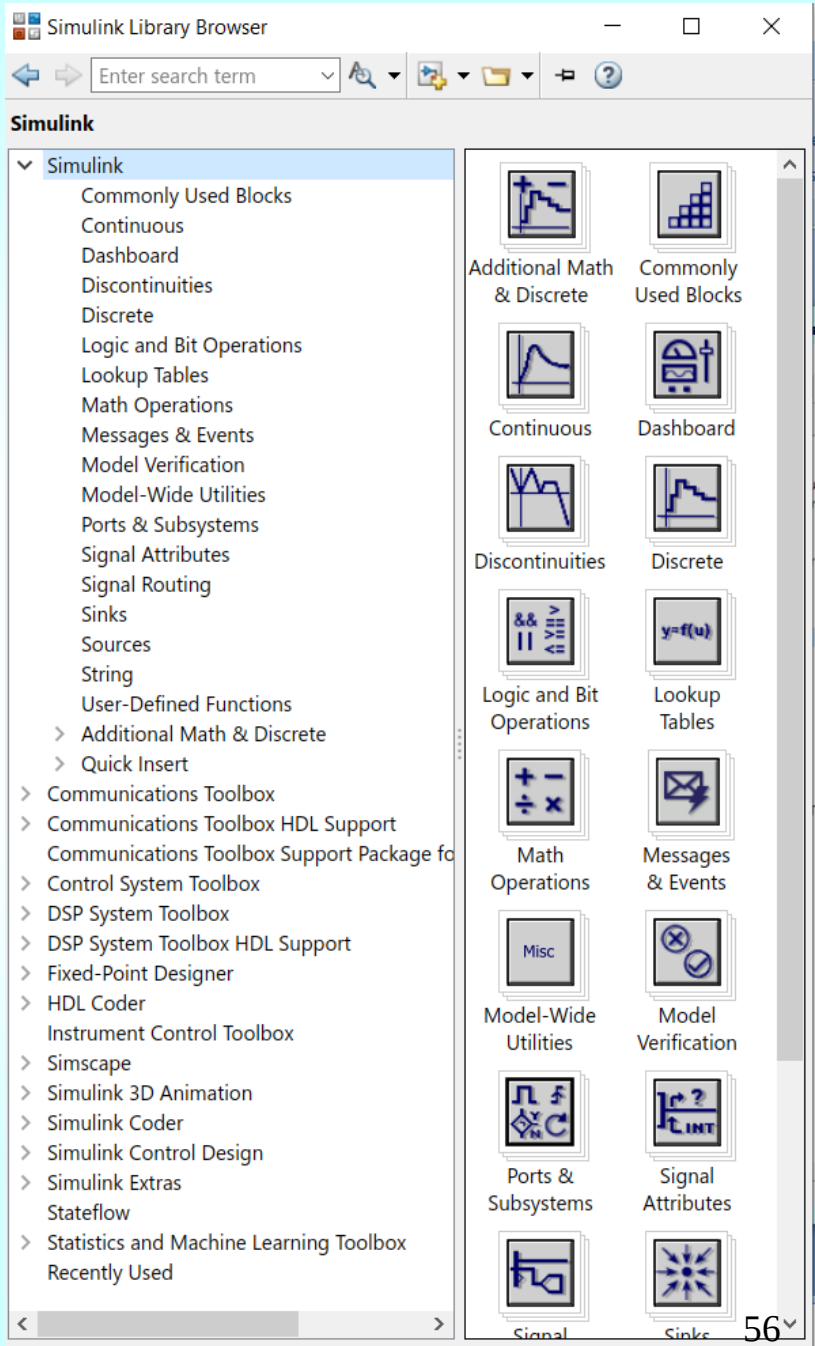

$\tau = RC = 1\text{ms}$

$\tau/10 = 0.1\text{ms}$

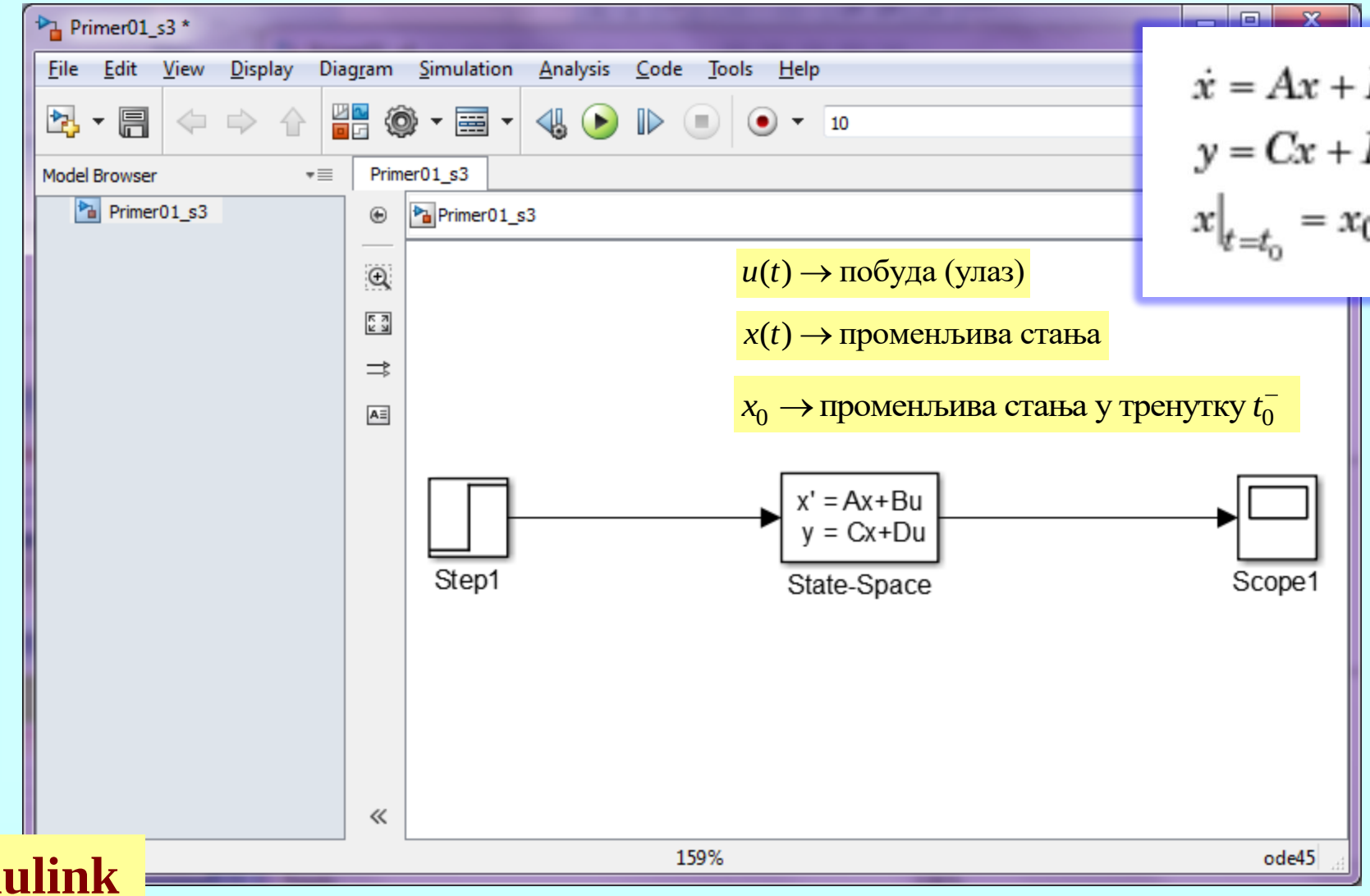
**Simscape > Electrical**

# Simulink

- Решавање кола може се извршити његовим свођењем на систем линеарних диференцијалних једначина
- Дати систем може се представити једноставним блоком са више улаза и излаза

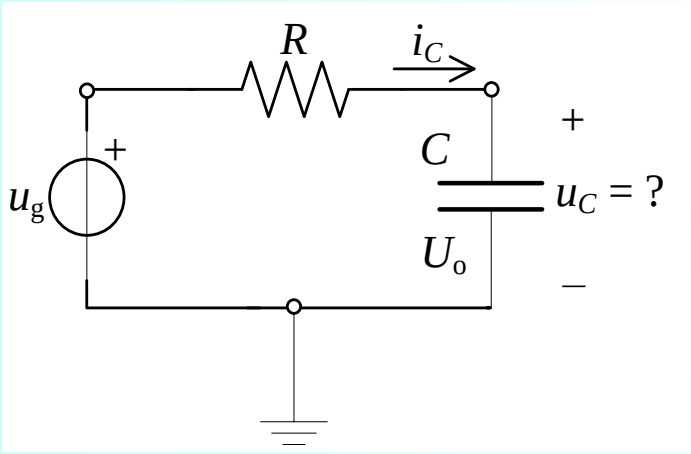


# Симулација електричног кола као уопштеног система коришћењем **Simulink**-а




**Simulink**

# Симулација електричног кола као уопштеног система коришћењем **Simulink**-а




$u = u_g(t) \rightarrow$ побуда (улаз)

$x = u_C(t) \rightarrow$ напон кондензатора (промењљива стања и одзив - излаз)

$x(t_0^-) = U_0 \rightarrow$ напон кондензатора у тренутку $t_0^-$

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$
$$x\big|_{t=t_0} = x_0,$$

коло је образовано у тренутку $t_0 = 0$

$$u_g(t) = Ri_C + u_C(t)$$
$$i_C = C\frac{du_C}{dt}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

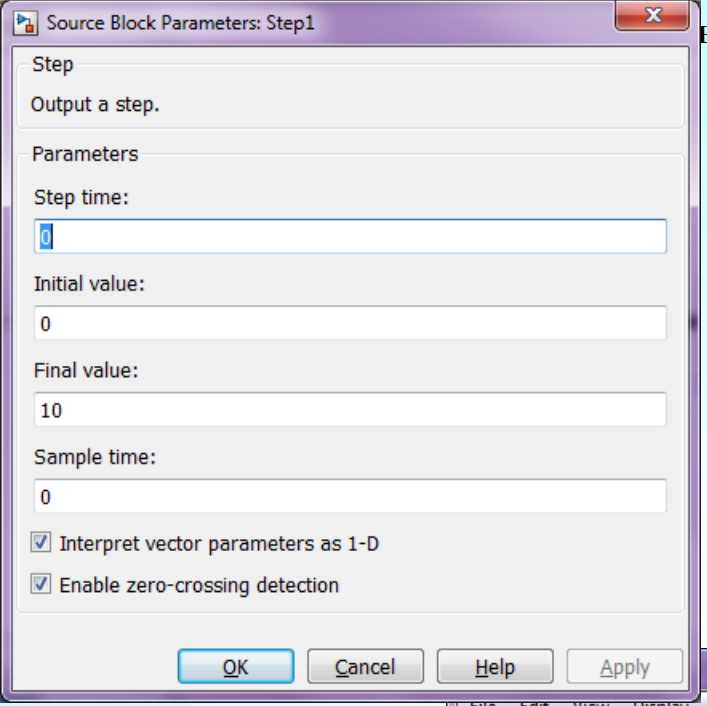
$$R = 1\,\text{k}\Omega$$
$$C = 1\,\mu\text{F}$$
$$u_g(t) = U\,h(t), U = 10\,\text{V}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

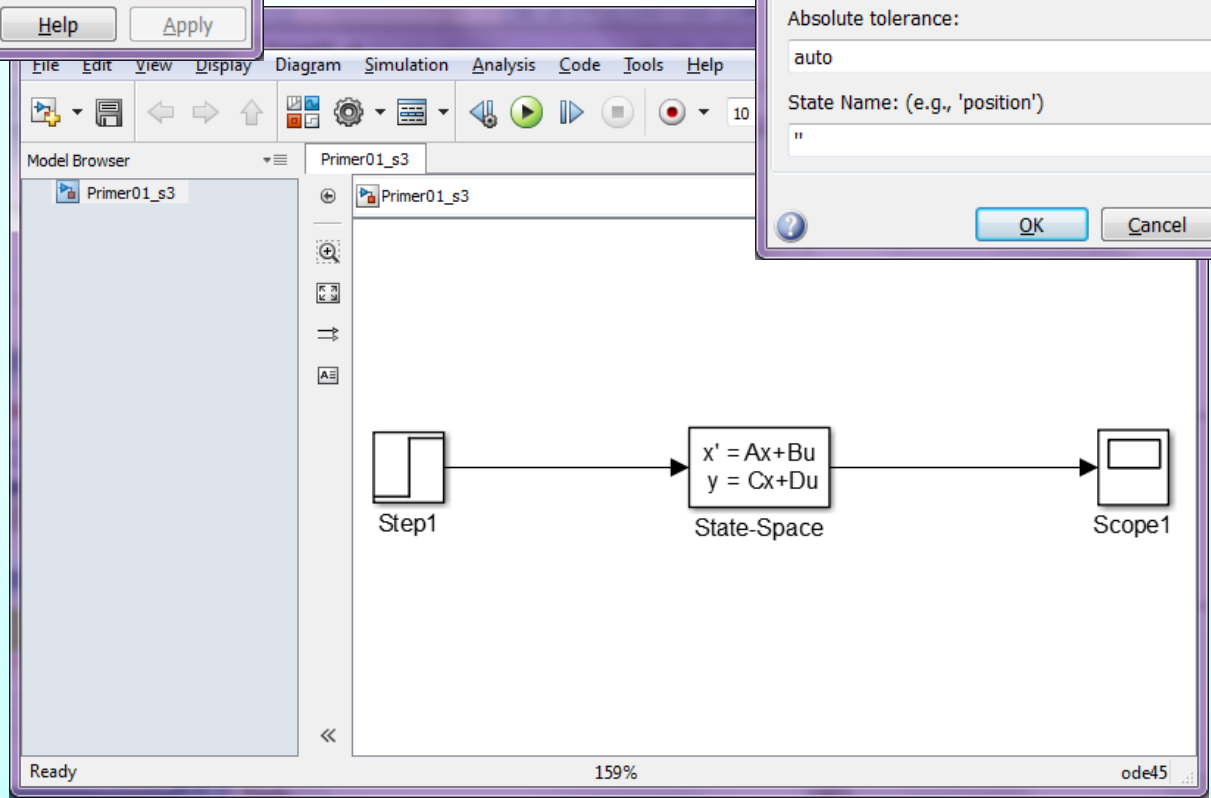
$$\frac{du_C(t)}{dt} = \frac{i_C}{C} = \frac{u_g(t) - u_C(t)}{RC} = -\frac{u_C(t)}{RC} + \frac{u_g(t)}{RC}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

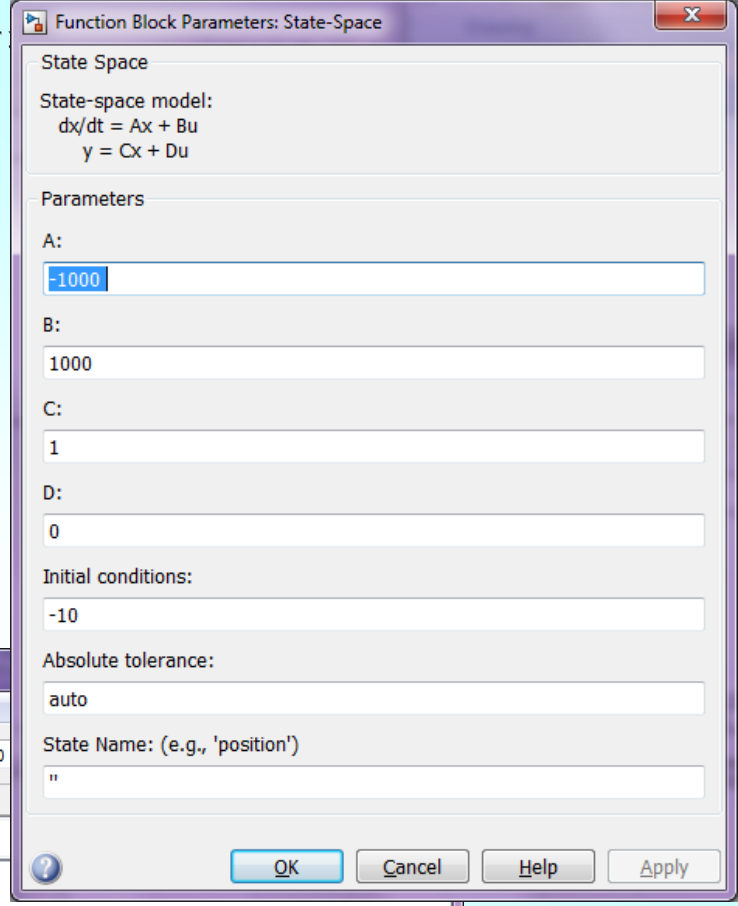
$$\frac{du_C(t)}{dt} = Au_C(t) + Bu_g(t) \Rightarrow A = -\frac{1}{RC} = -1000, B = 1000$$
$$u_C(t) = Cu_C(t) \Rightarrow C = 1, D = 0$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

**Simulink**

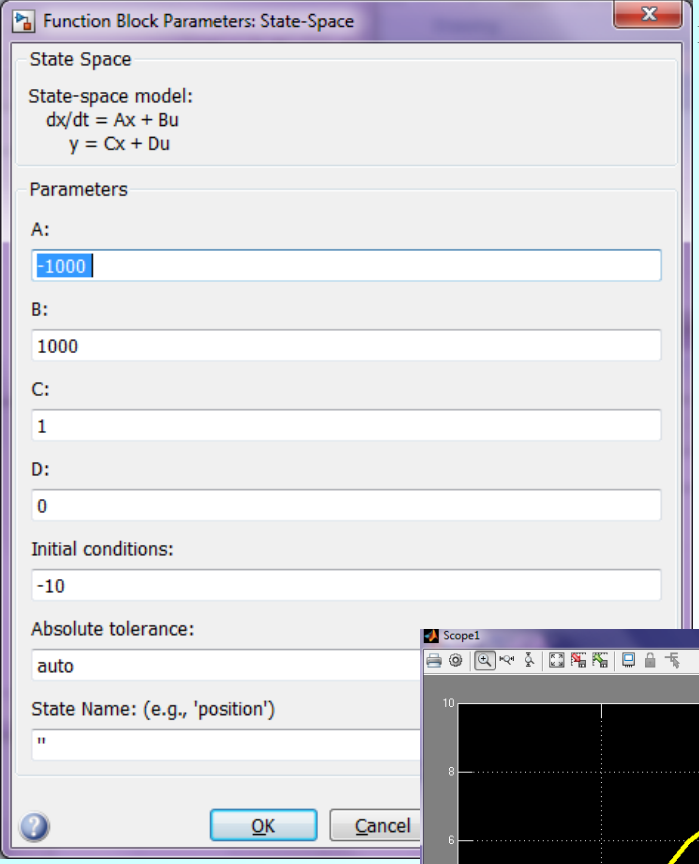
# Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

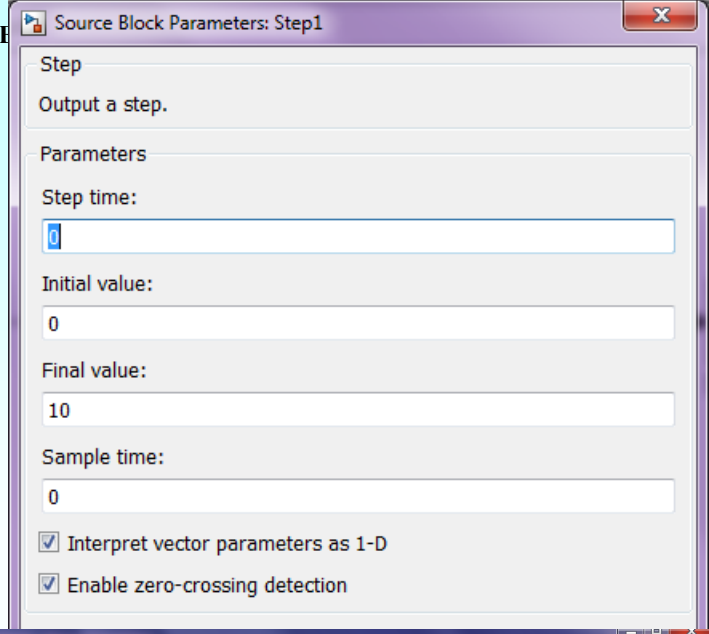


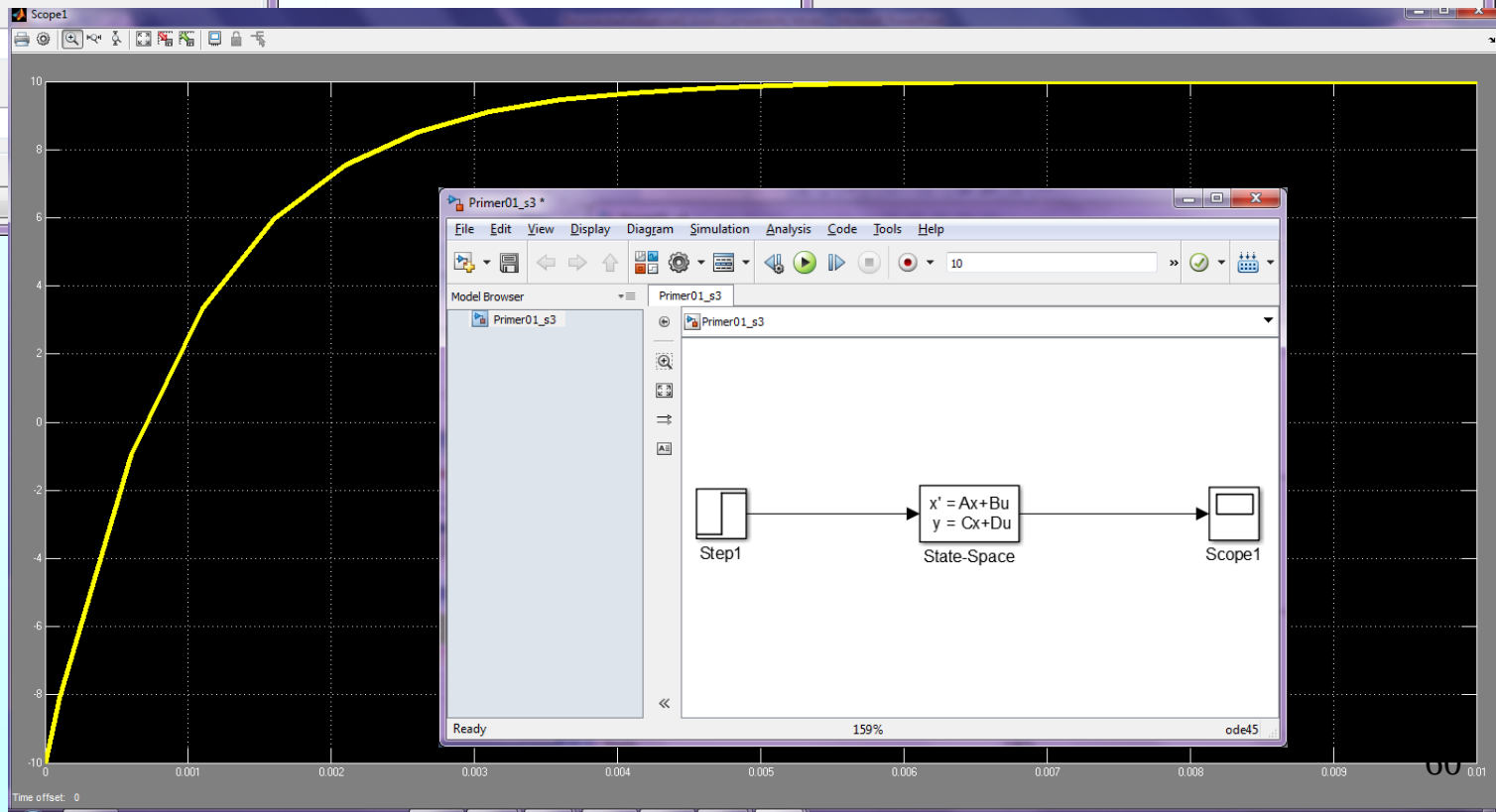



# Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

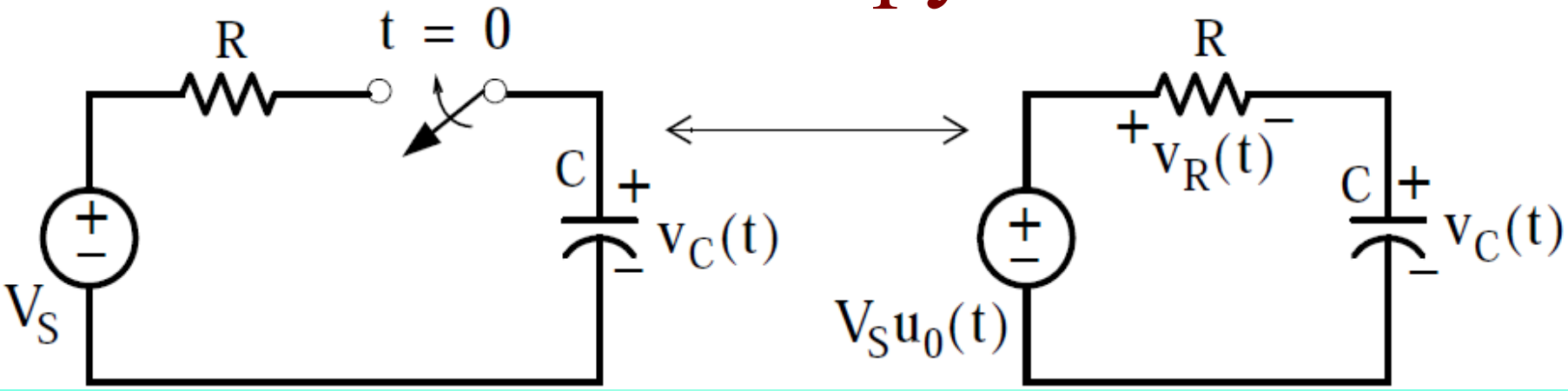



**Simulink**

# Решимо “ручно”




$$v_R + v_C = V_S u_0(t)$$

$$i = i_C = C\frac{dv_C}{dt}$$

$$v_R = Ri = RC\frac{dv_C}{dt}$$

$$RC\frac{dv_C}{dt} + v_C = V_S u_0(t)$$

$t > 0$

$$RC\frac{dv_C}{dt} + v_C = V_S$$

$$v_C(t) = (V_S - V_S\, e^{-(1/RC)t})u_0(t)$$

# MATLAB
# Symbolic Math Toolbox (Live Script)

- Библиотека за симболички рачун (алгебарске и диференцијалне једначине)
- Омогућава нумеричку анализу резултата прорачуна

Live Editor - D:\Engineering_Work\ETF\Teaching\PRK\RCKolo_v0.mlx

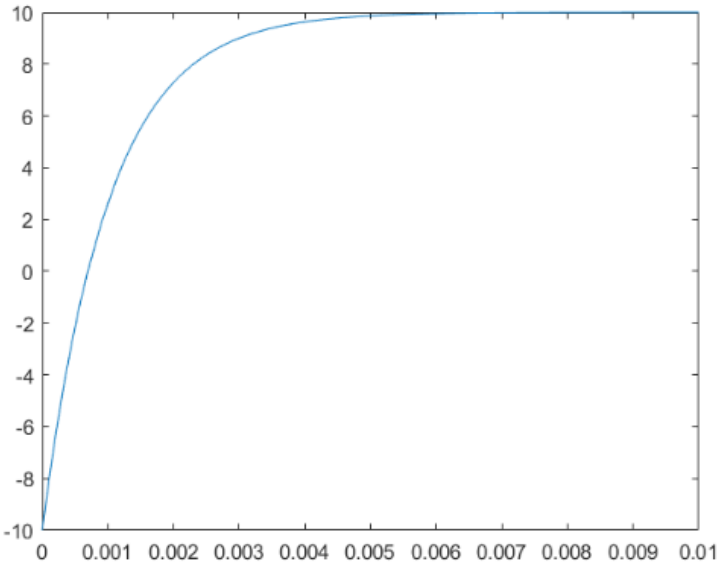
pluto1.m | template1.m | RCKolo_v0.mlx

```
1  syms v_c(t)
2  ode = diff(v_c,t) ==-1000*v_c+10000
3  cond = v_c(0)==-10
4  v_csol = dsolve(ode,cond)
5
6  fplot(v_csol, [0 0.01])
```

$$\frac{\partial}{\partial t} v_c(t) = 10000 - 1000\, v_c(t)$$

cond = $v_c(0) = -10$

v_csol = $10 - 20\, e^{-1000\, t}$




**Simbolic Math Toolbox**

# wxMaxima

wxMaxima 20.06.6 [ unsaved* ]

File Edit View Cell Maxima Equations Algebra Calculus Simplify List Plot Numeric Help

Maths

Mathematical Symbols

Plot using Draw

| 2D | 3D |
|---|---|
| Expression | Implicit Plot |
| Parametric Plot | Points |
| Diagram title | Axis |
| Contour | Plot name |
| Line color | Fill color |
| Grid | Accuracy |

```
(%i1) jednacine: [ug=R·iC+uC, iC=C·'diff(uC,t)];
```

$$(\%o1)\quad \left[ug = uC + R\,iC,\ iC = C\left(\frac{d}{d\,t}\,uC\right)\right]$$

```
(%i2) jednacineDuC: jednacine, 'diff(uC,t)=DuC;
```

$$(\%o2)\quad [ug = uC + R\,iC,\ iC = C\,DuC]$$

```
(%i3) JednacineIzvoda: eliminate(jednacineDuC,
      [iC]);
```

$$(\%o3)\quad [-ug + uC + C\,DuC\,R]$$

```
(%i4) jednacineStanja: linsolve(JednacineIzvoda, DuC);
```

$$(\%o4)\quad \left[DuC = \frac{ug - uC}{C\,R}\right]$$

```
(%i5) jednacineDiff: jednacineStanja, DuC='diff(uC, t);
```

$$(\%o5)\quad \left[\frac{d}{d\,t}\,uC = \frac{ug - uC}{C\,R}\right]$$

```
(%i6) zamene: [ug=U];
```

(%o6) $[ug=U]$

```
(%i7) vrednosti: [R=1000, C=10^(-6), U=10, U0=-10];
```

(%o7) $[R=1000, C=\frac{1}{1000000}, U=10, U0=-10]$

```
(%i8) JednacineDiffZamena: jednacineDiff, zamene;
```

(%o8) $[\frac{d}{dt} uC=\frac{U-uC}{CR}]$

```
(%i9) ode2(JednacineDiffZamena, uC, t);
```

(%o9) $uC=\%e^{-\frac{t}{CR}}\left(U\ \%e^{\frac{t}{CR}}+\%c\right)$

```
(%i10) ic1(%, t=0, uC=U0);
```

(%o10) $uC=\%e^{-\frac{t}{CR}}\left(U\ \%e^{\frac{t}{CR}}+U0-U\right)$

```
(%i11) uCt: ev(%, vrednosti);
```

(%o11) $uC=\%e^{-1000\,t}\left(10\ \%e^{1000\,t}-20\right)$

```
(%i17) wxplot2d(rhs(uCt), [t,0,0.01],
       [xlabel," t [s] "],
       [ylabel," uC [V] "],
       [xtics, 0, 0.002, 0.01],
       [legend, "Napon kondenzatora"], grid2d)$
```