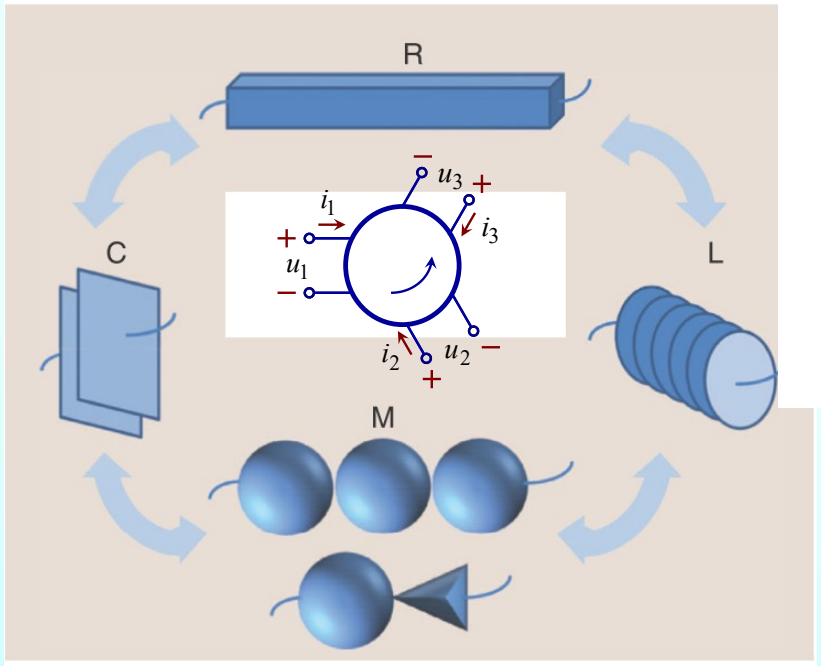
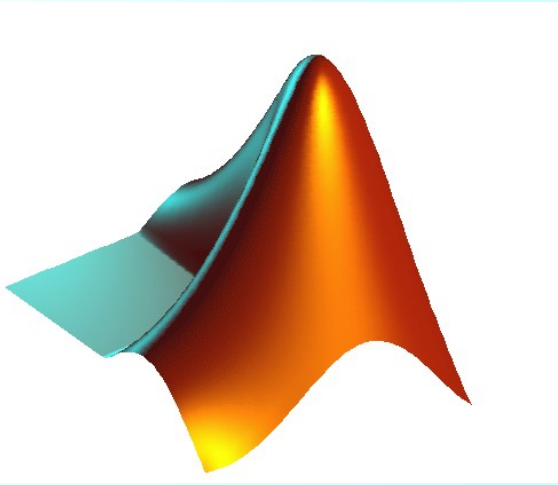
Практикум из рачунарске анализе трофазних кола

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.

Практикум из рачунарске анализе трофазних кола 19E072ПРТК

- **Наставници:** Др **Милка Потребић Иваниш**, редовни професор, соба 64 (milka_potrebic@etf.rs);
  Др **Никола Баста**, доцент, лаб. 63 (nbasta@etf.rs).
- **Асистенткиња: Ања Ковачевић**, мс. инж., соба 95 (anja@etf.rs)
- **Сарадница у настави: Анђела Нинковић**, дипл. инж., лаб. 63 (andjela@etf.rs)

- 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.** Рачунарска учионица (70, РЦ, 64б);
- **Пратити** званично представљање предмета и објављивање општих службених порука на адреси **http://tek.etf.rs/** ;

Начин полагања испита

- **Структура оцене**

Активност	Максимални број поена	Опис / Напомена
Предиспитне обавезе	**70 поена**	Кратки задаци на часовима и/или домаћи задаци (максимално 3 домаћа задатка).
Испит (пројекат)	**30 поена**	Израда на рачунару уз коришћење литературе у сваком испитном року.
Бонус	*10 поена*	MATLAB Onramp сертификат (добровољно).

За издраду домаћих задатака јавити се и-мејлом Милки Потребић Иваниш.

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

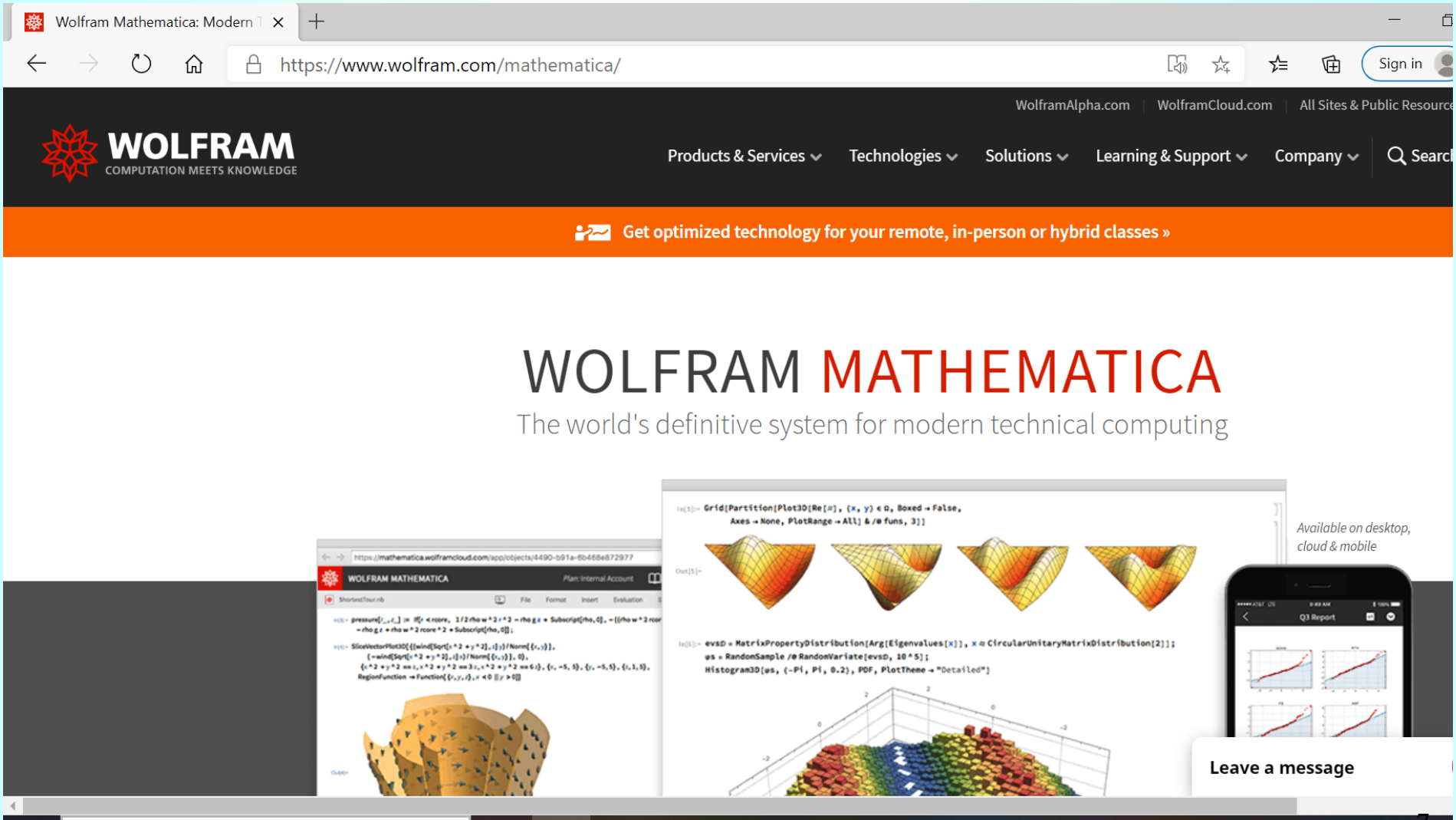
Free/Libre Open Source Software (FLOSS)

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:

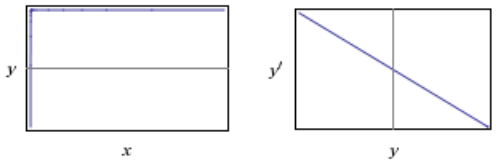
$\{y'(x) = 10\,000 - 1000\, y(x),\ y(0) = -10\}$

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

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

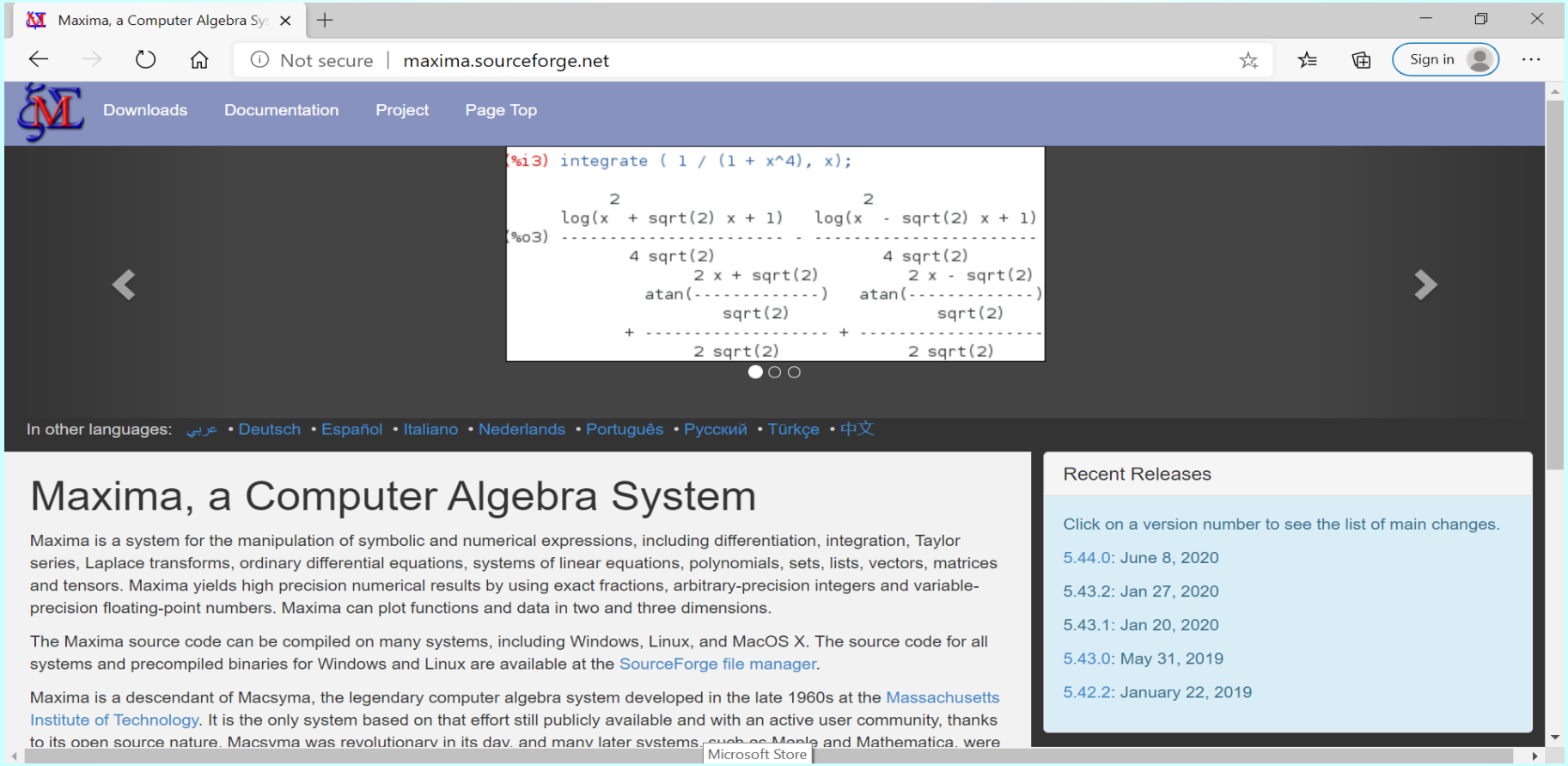
$y(x) = 10 - 20\, e^{-1000\, x}$

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);`

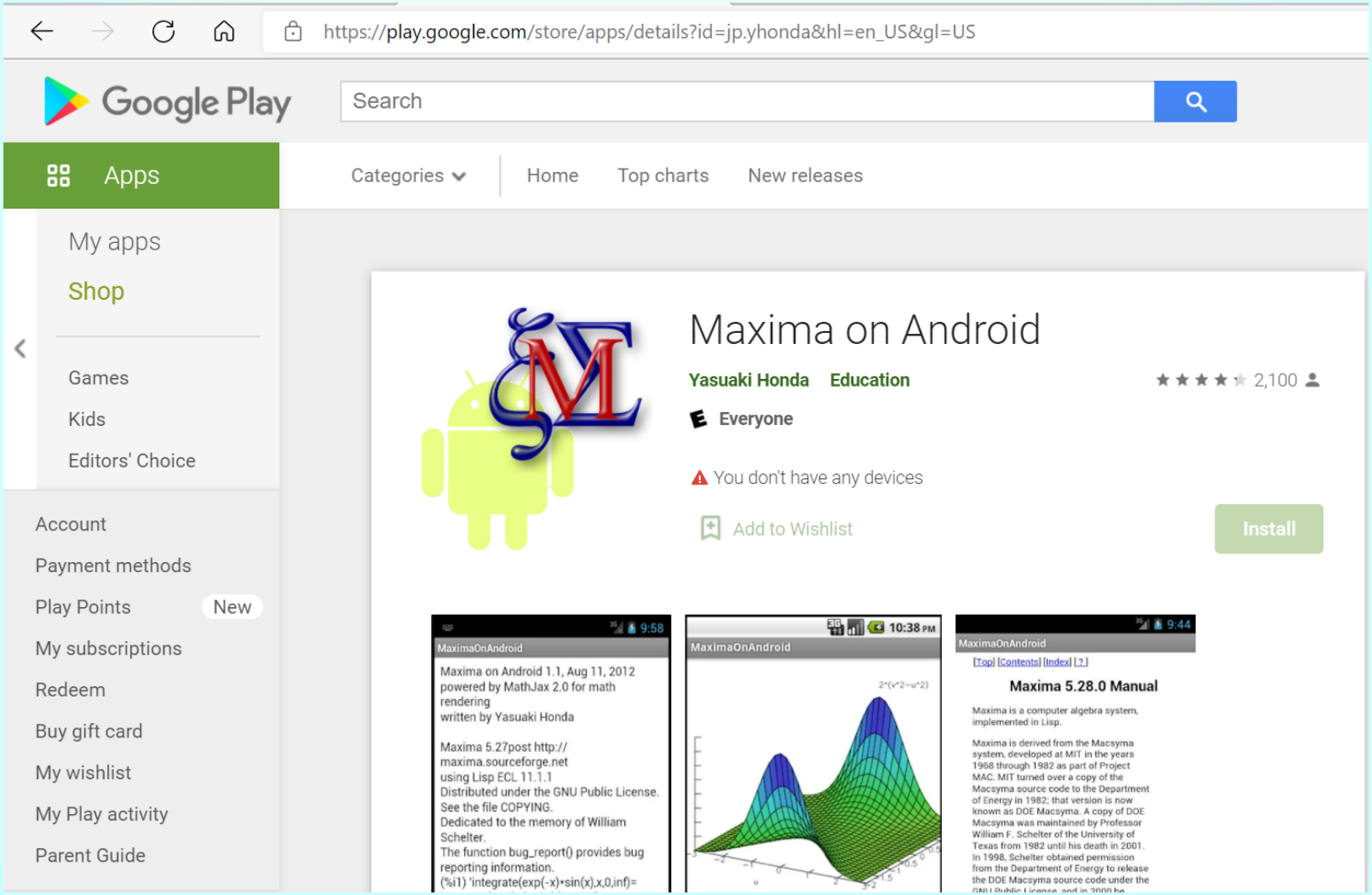
(%o2) $\left[x=-\frac{\sqrt{7}\,i-1}{2},x=\frac{\sqrt{7}\,i+1}{2}\right]$

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

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

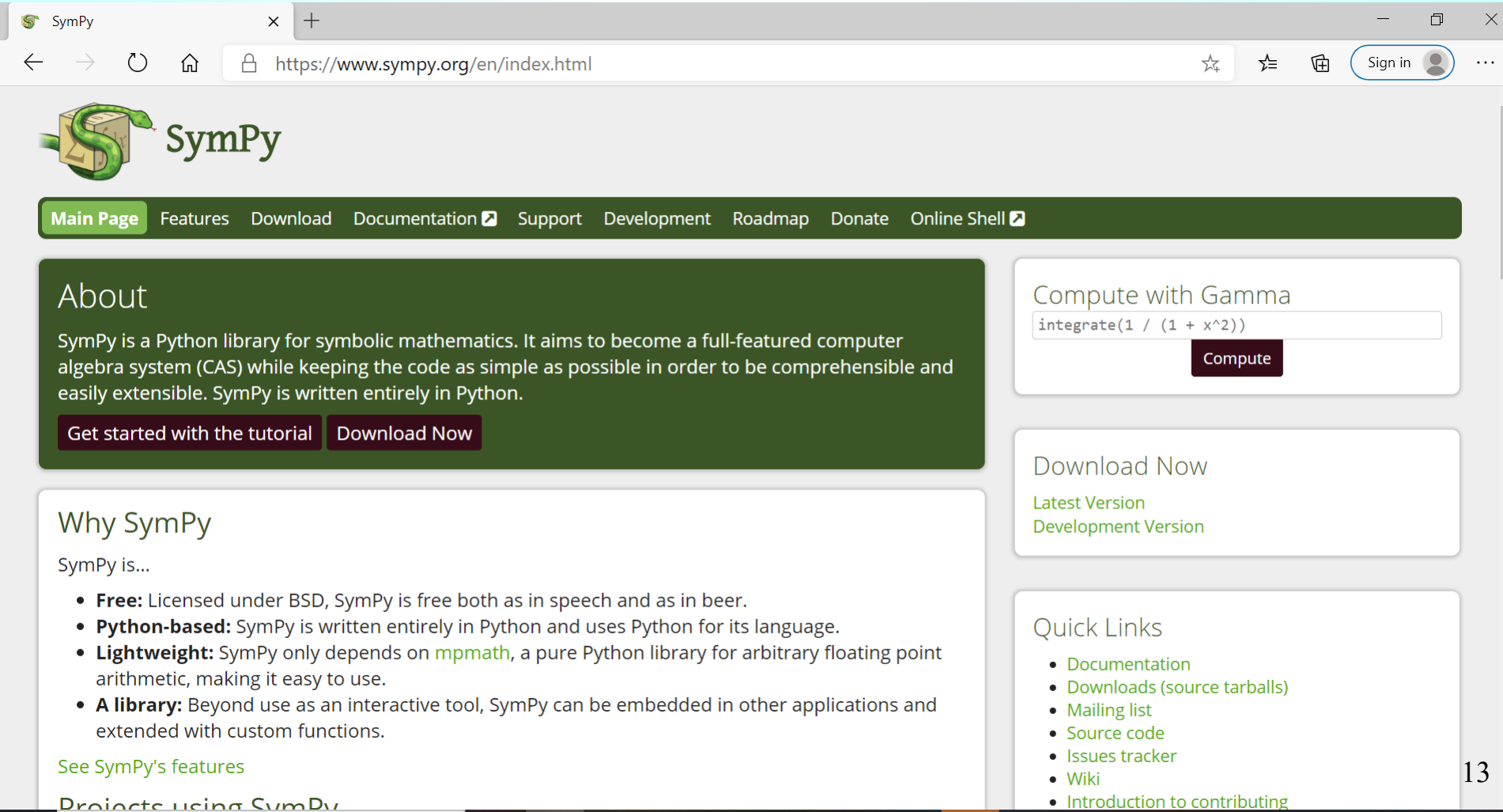
Maxima on Android

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



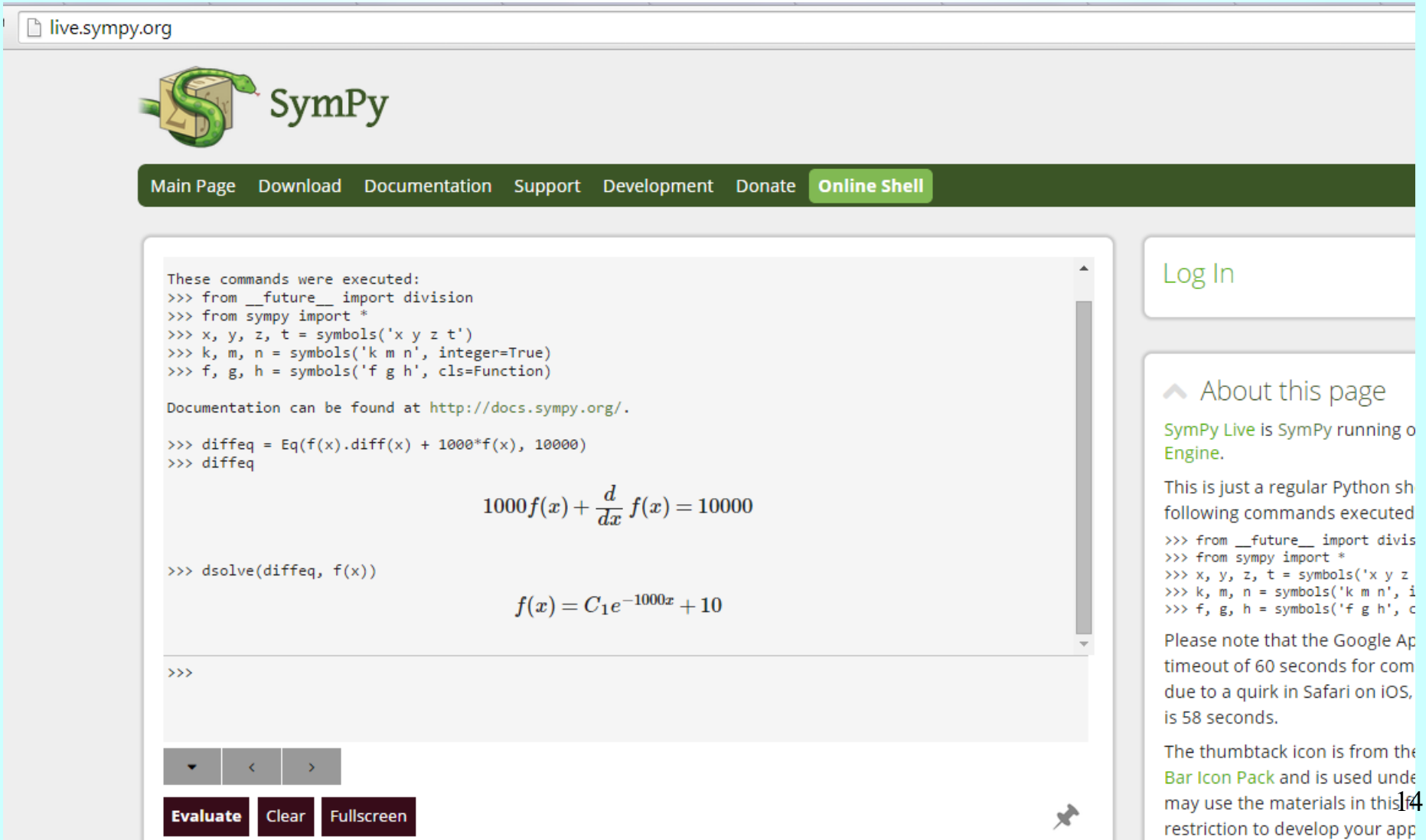
SymPy

www.sympy.org/



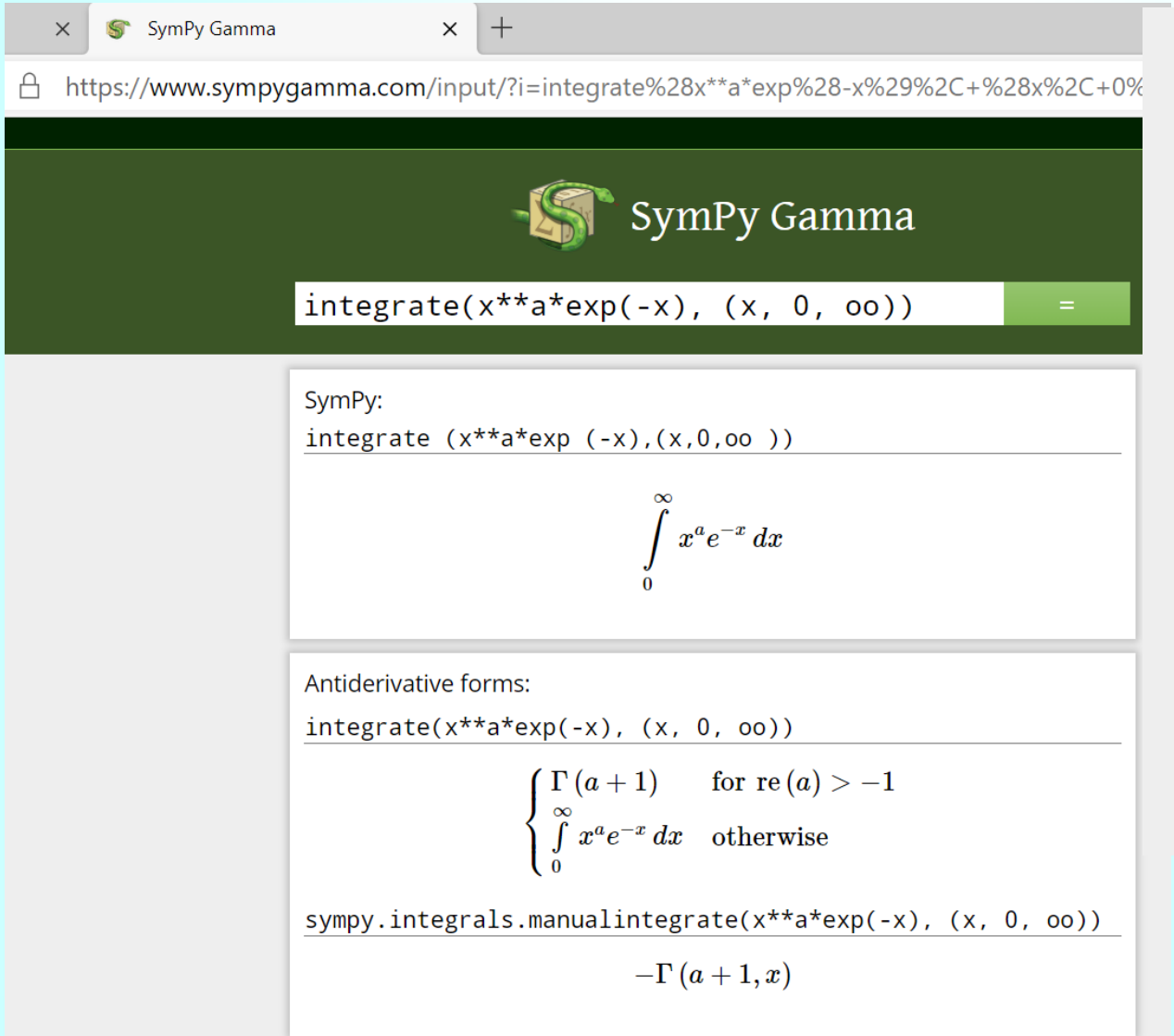
SymPy live

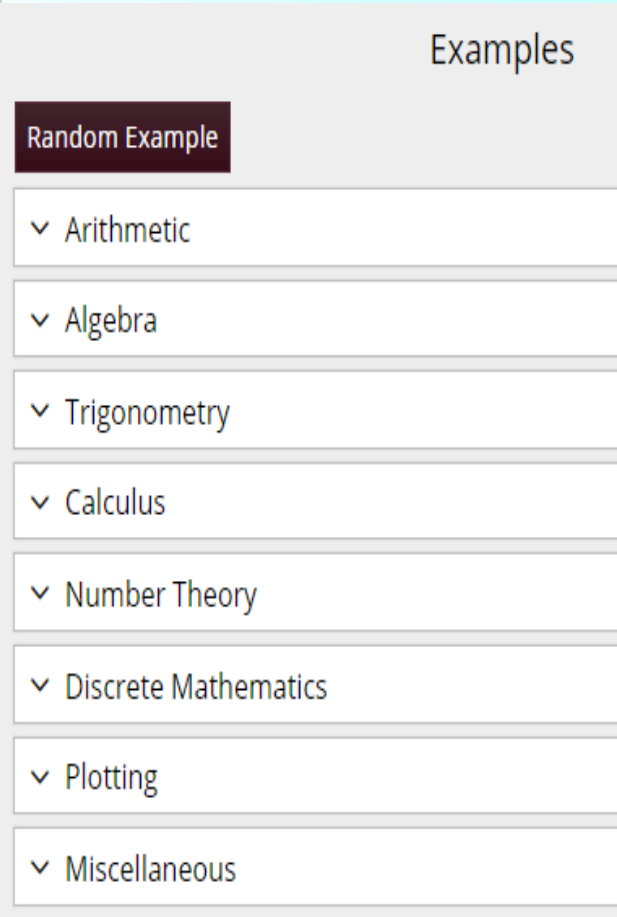
live.sympy.org

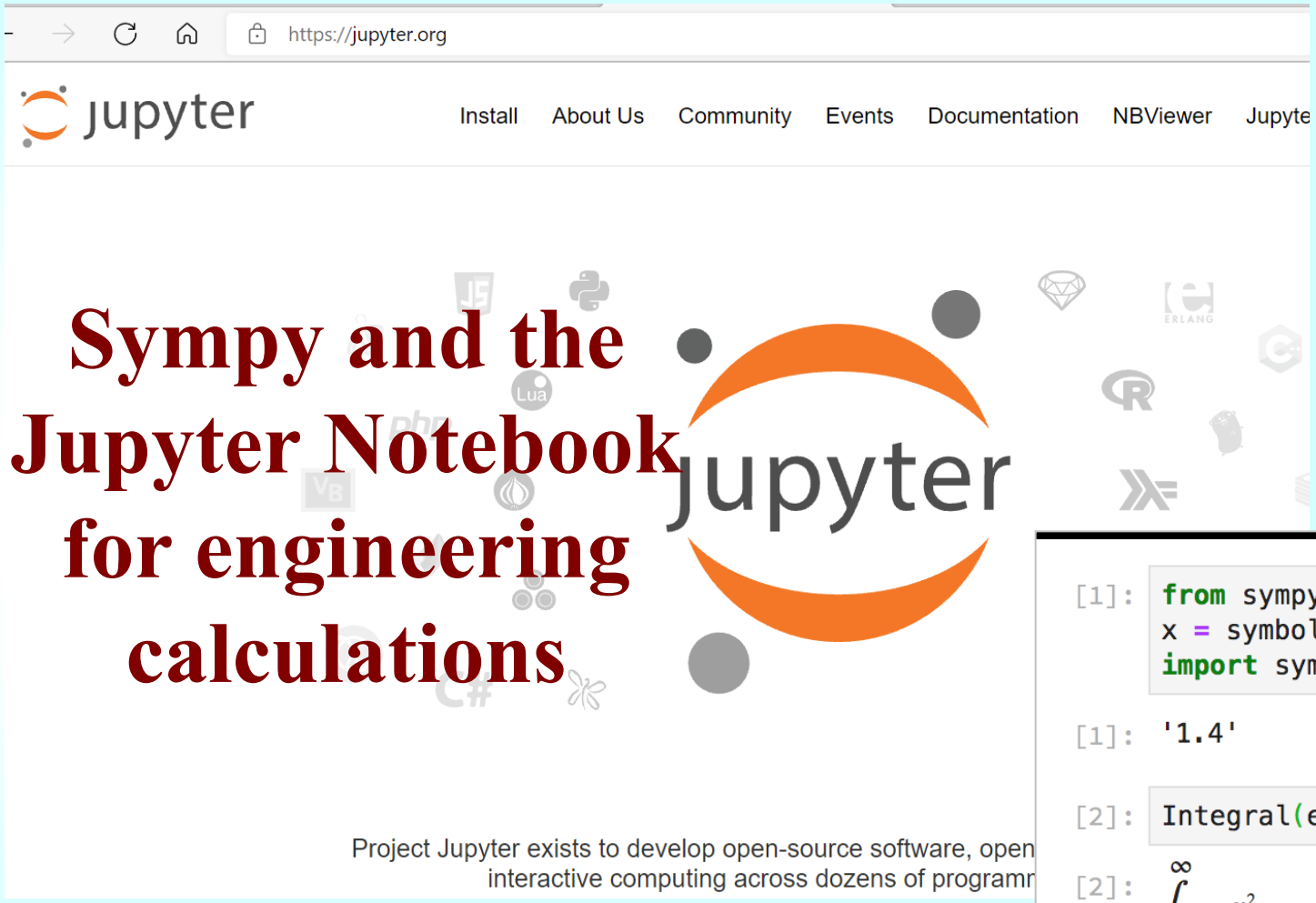


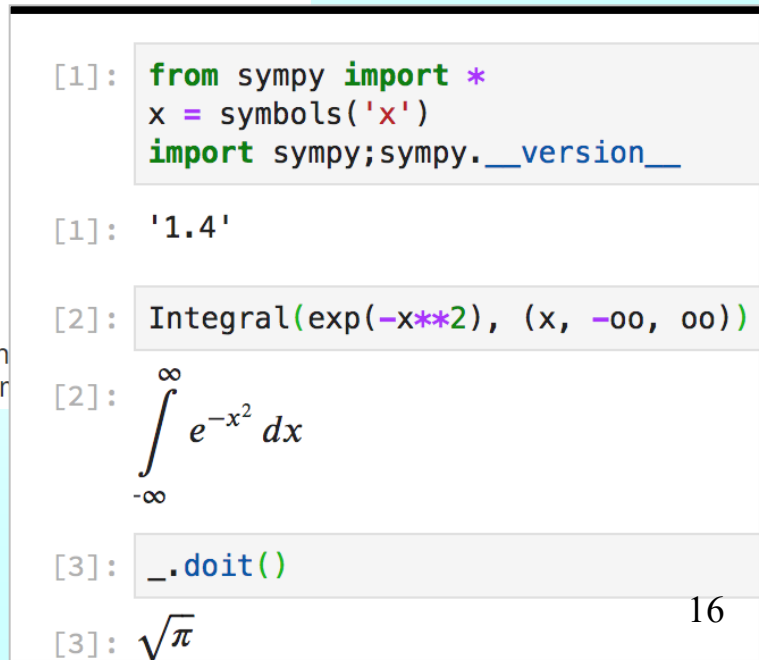
SymPy Gamma

https://www.sympygamma.com/

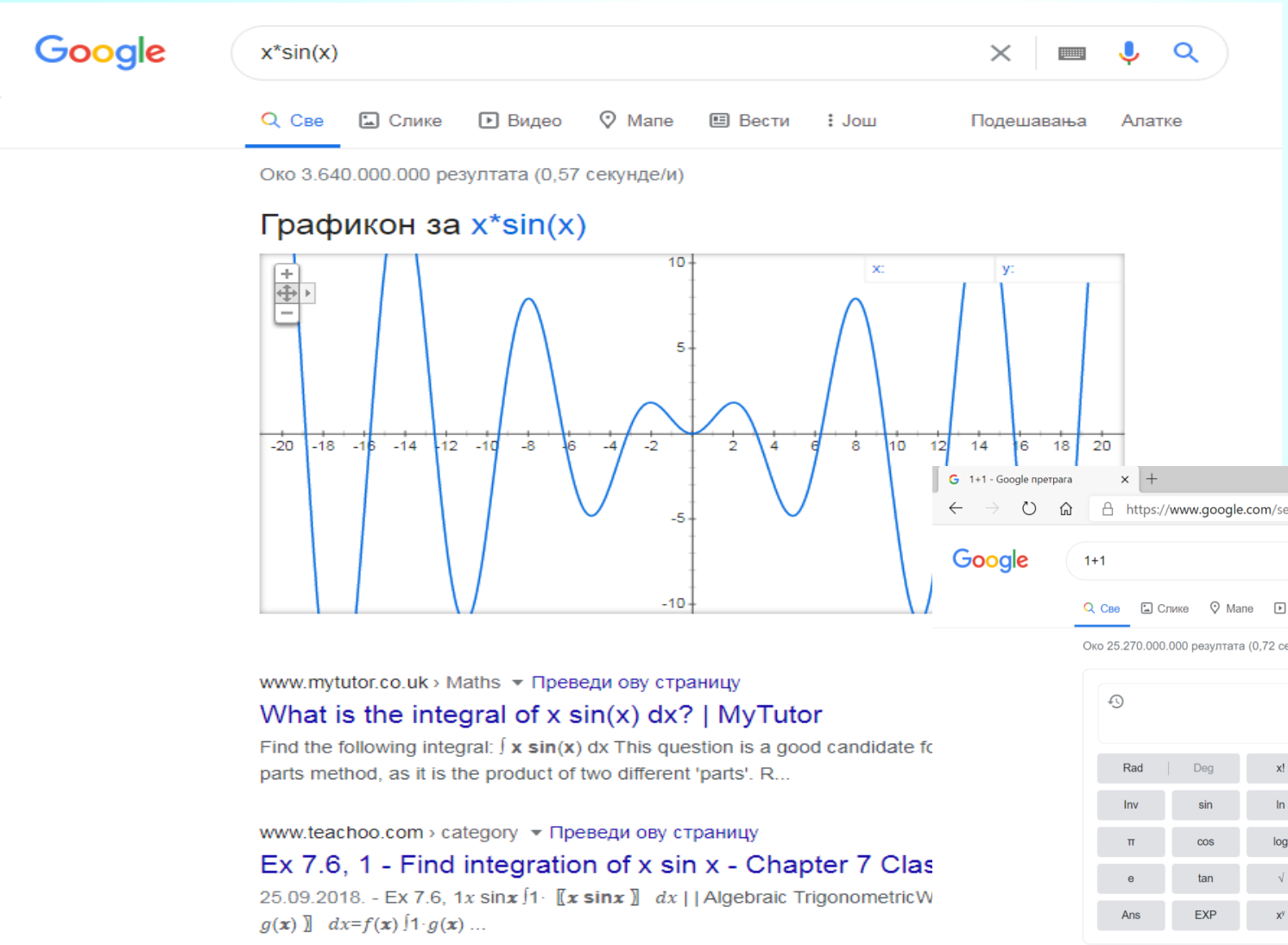


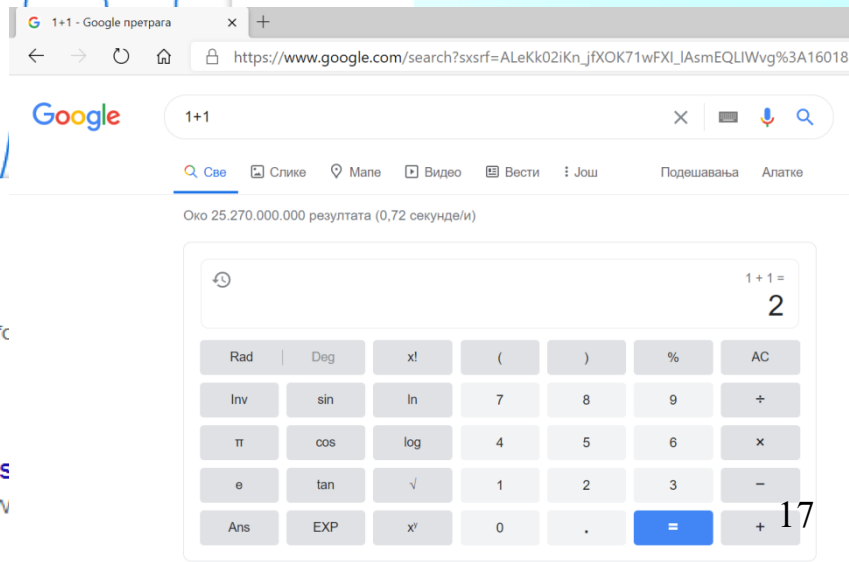



https://jupyter.org
jupyter
Install
About Us
Community
Events
Documentation
NBViewer
Jupyte
Sympy and the Jupyter Notebook for engineering calculations
jupyter
Project Jupyter exists to develop open-source software, open
interactive computing across dozens of programm


[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]:
$\sqrt{\pi}$

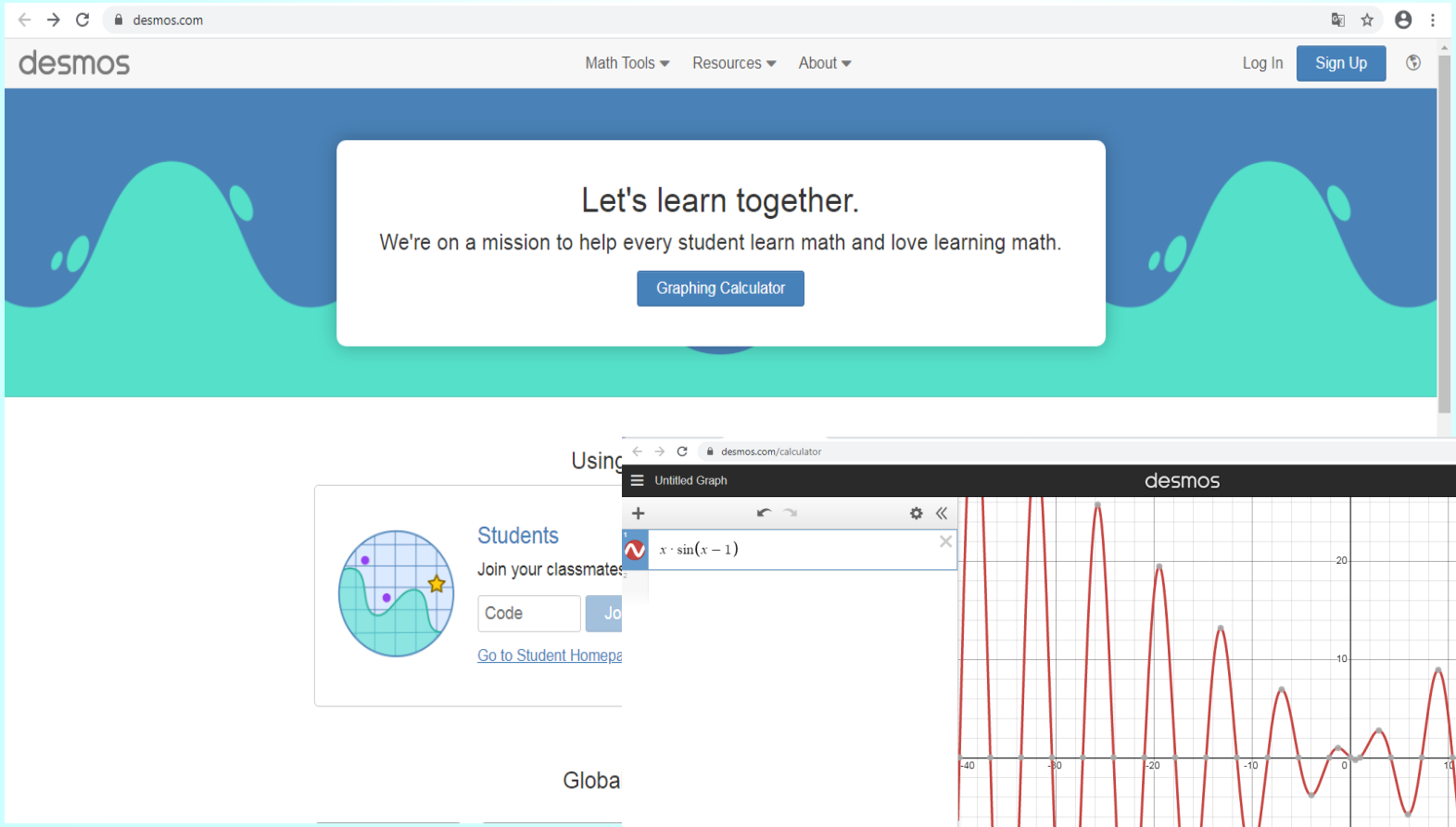
Google калкулатор

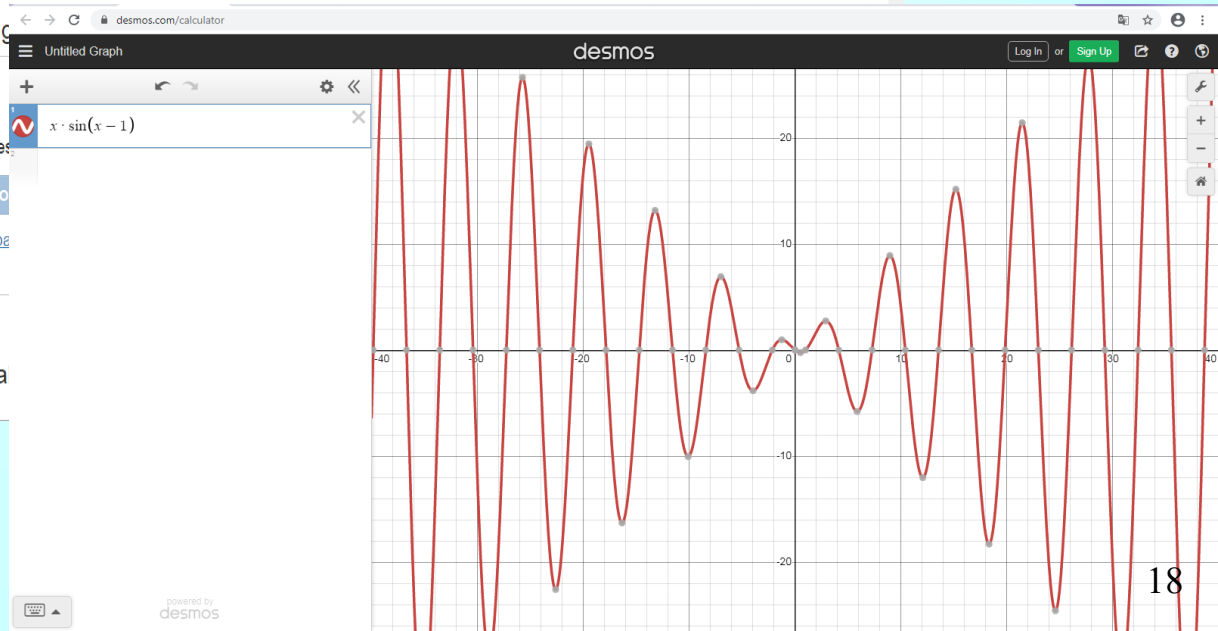




Graphing Calculator – Desmos

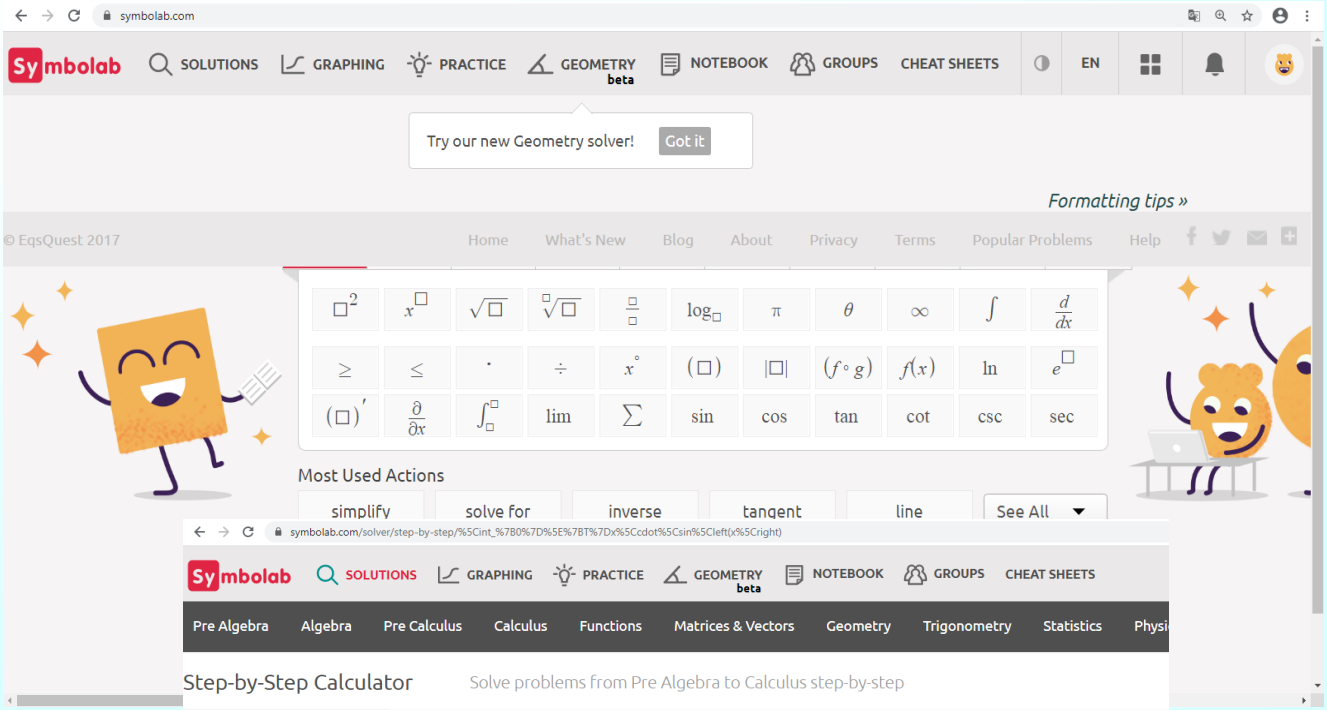
https://www.desmos.com/calculator

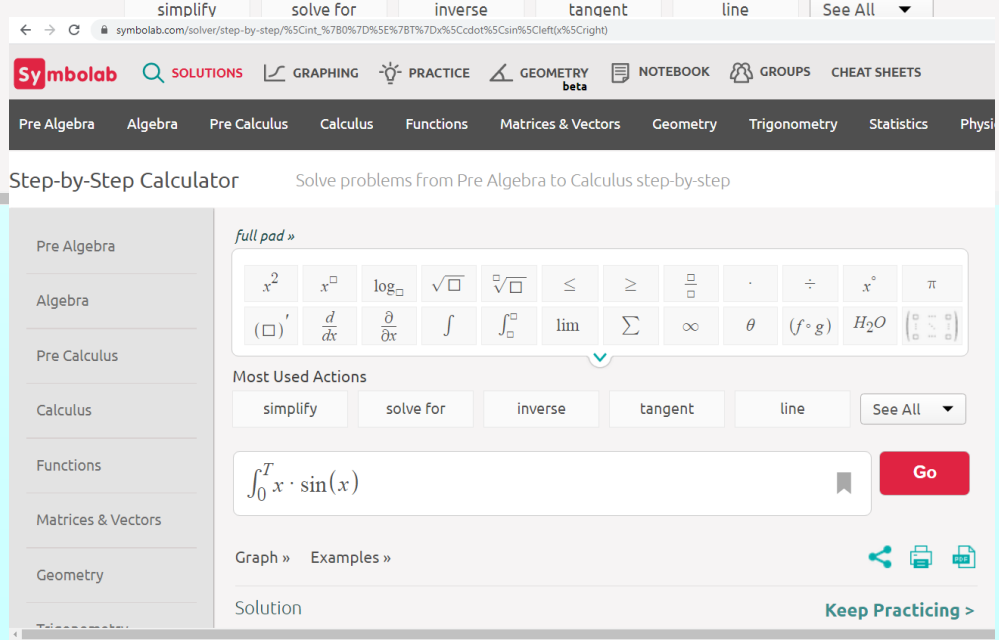


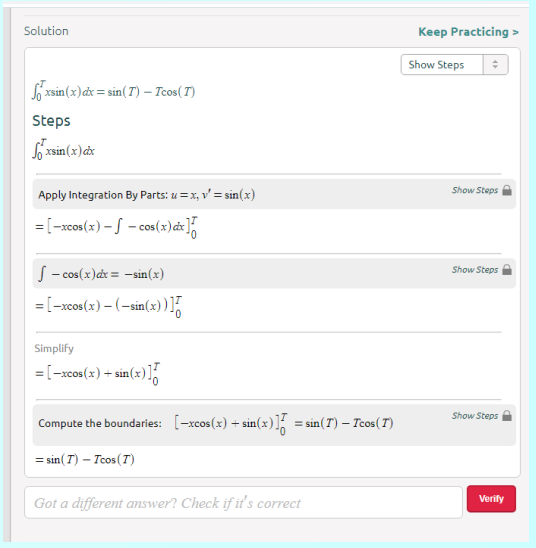


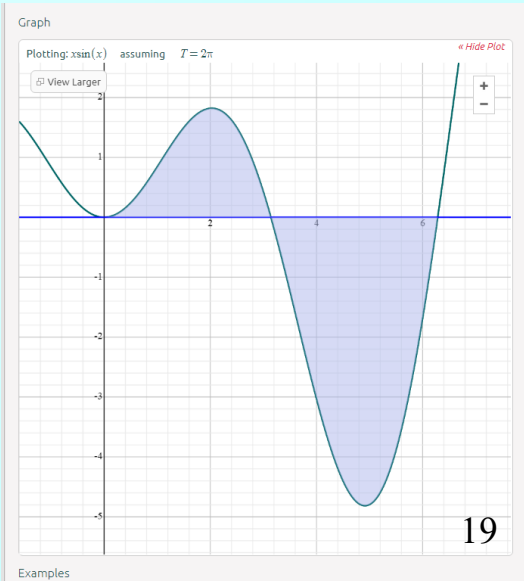
Symbolab Math Solver - Step by Step calculator

https://www.symbolab.com/



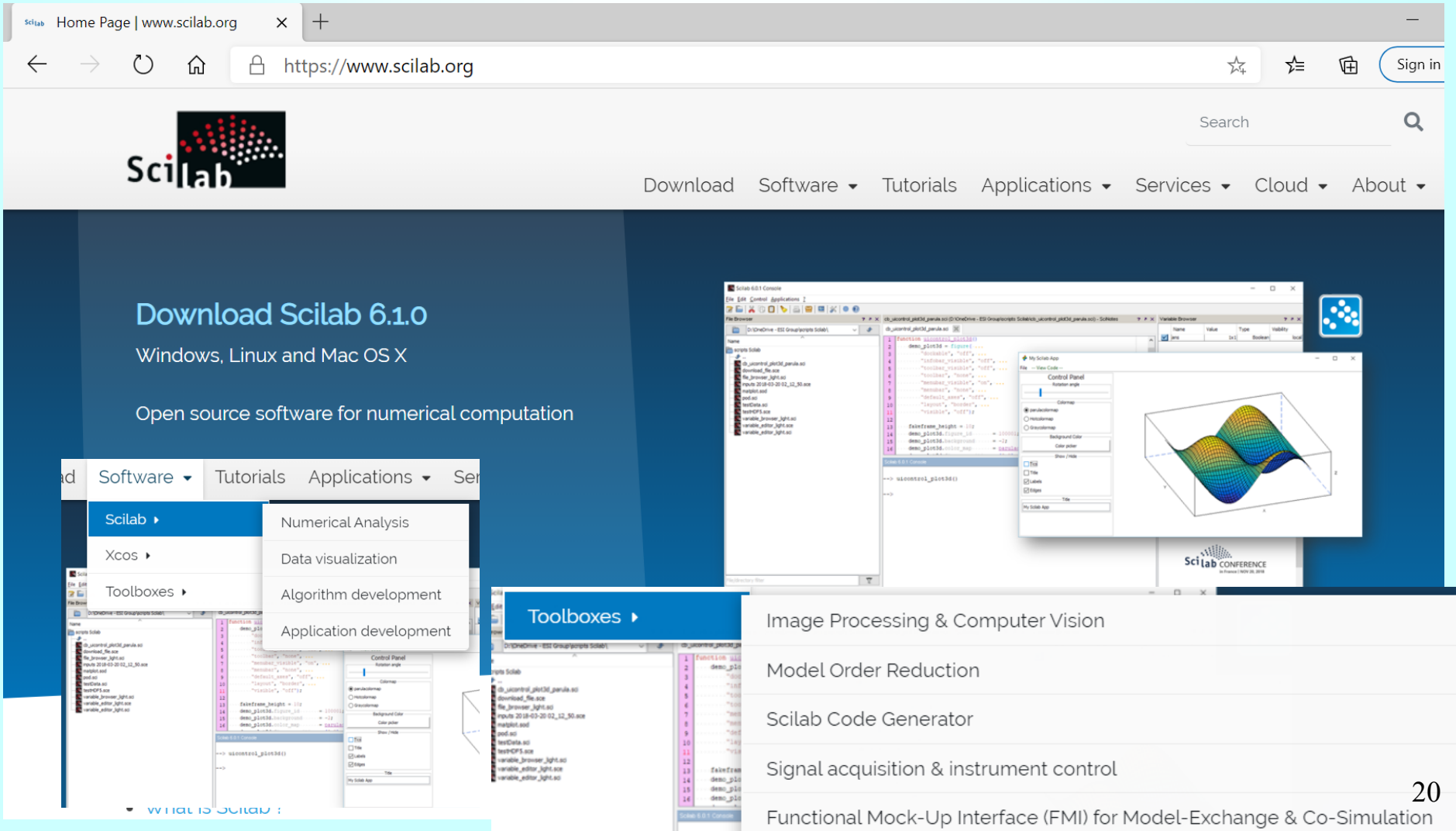






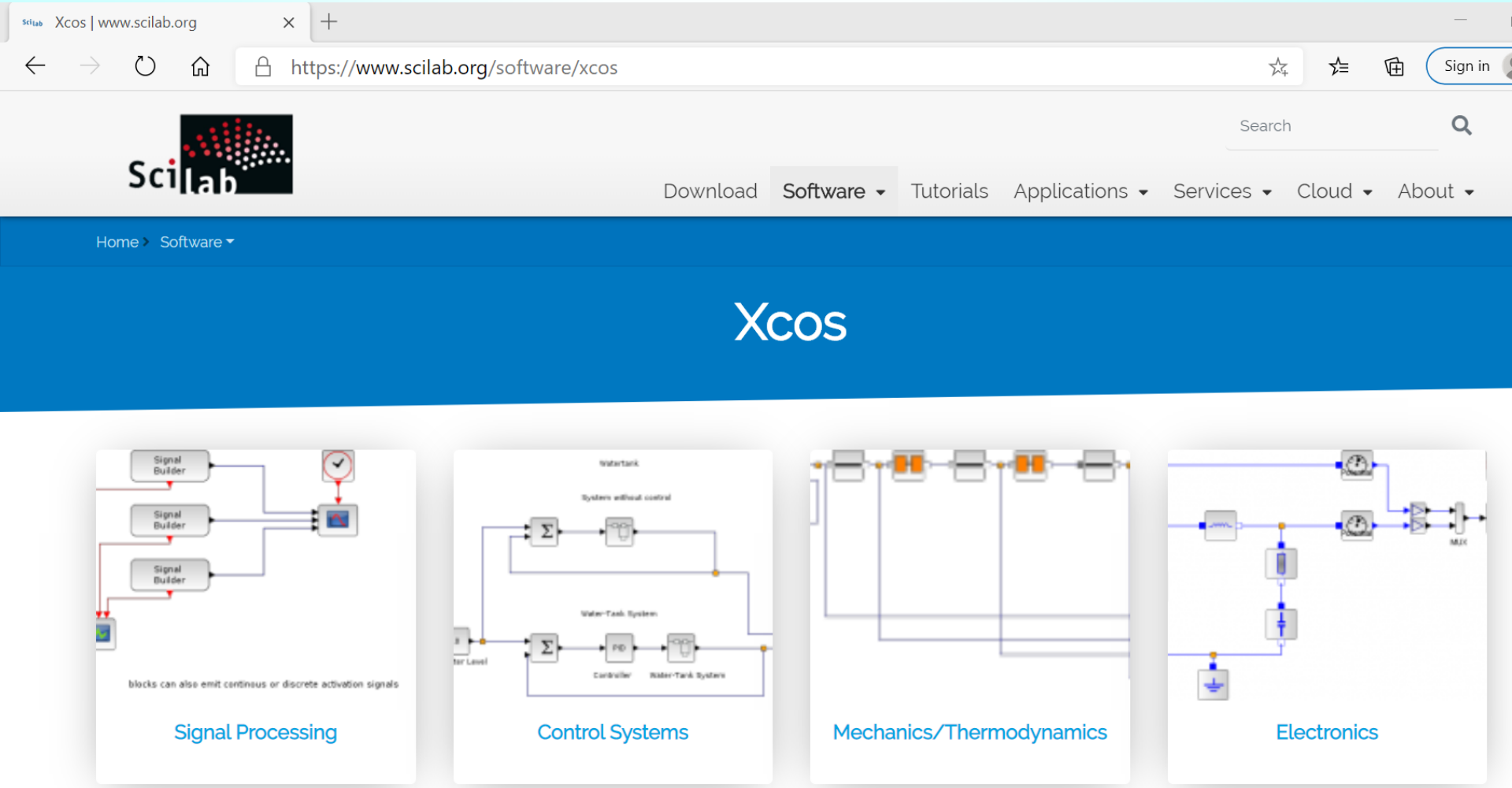
SciLab

https://www.scilab.org/



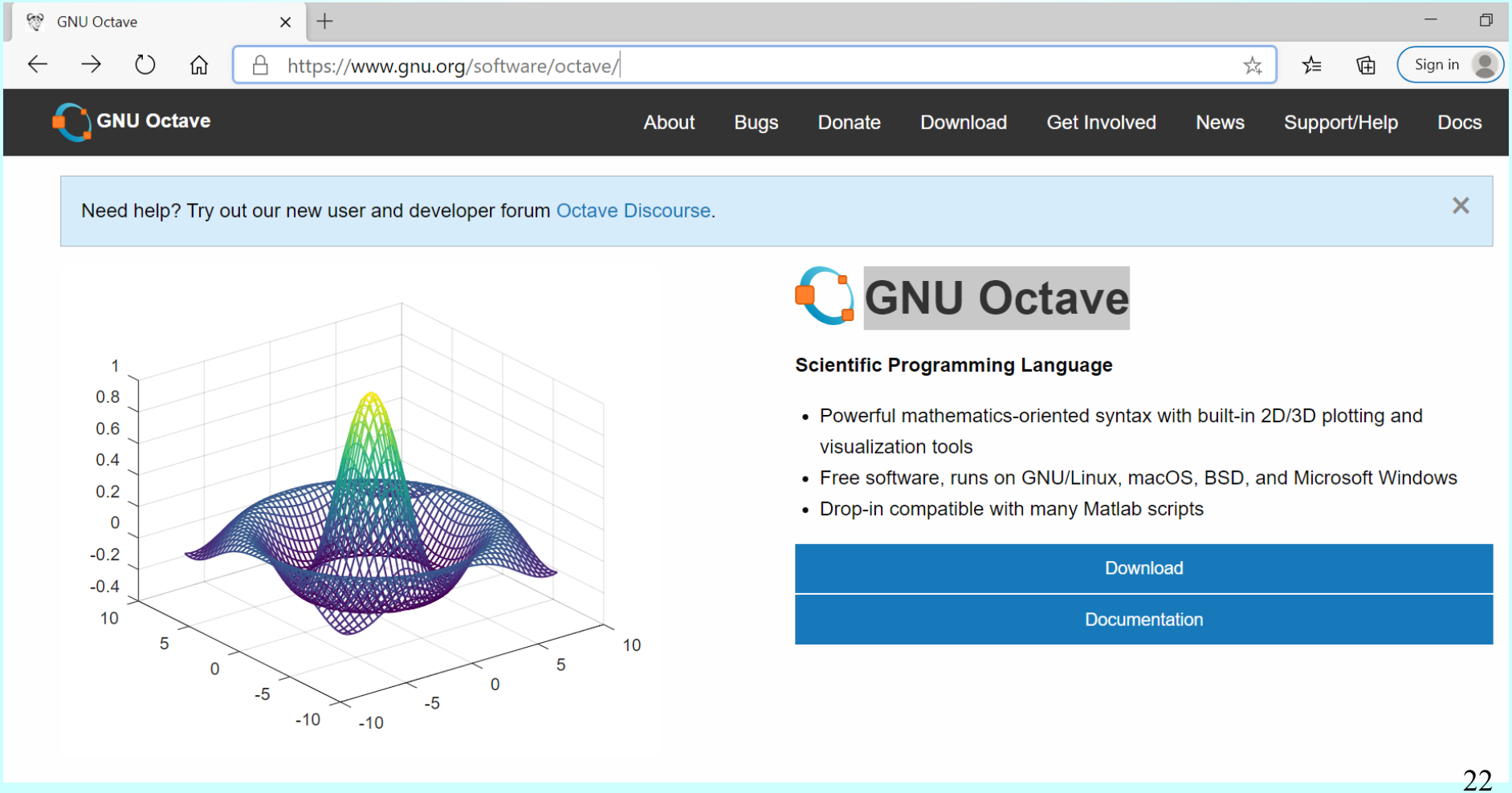
Xcos

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



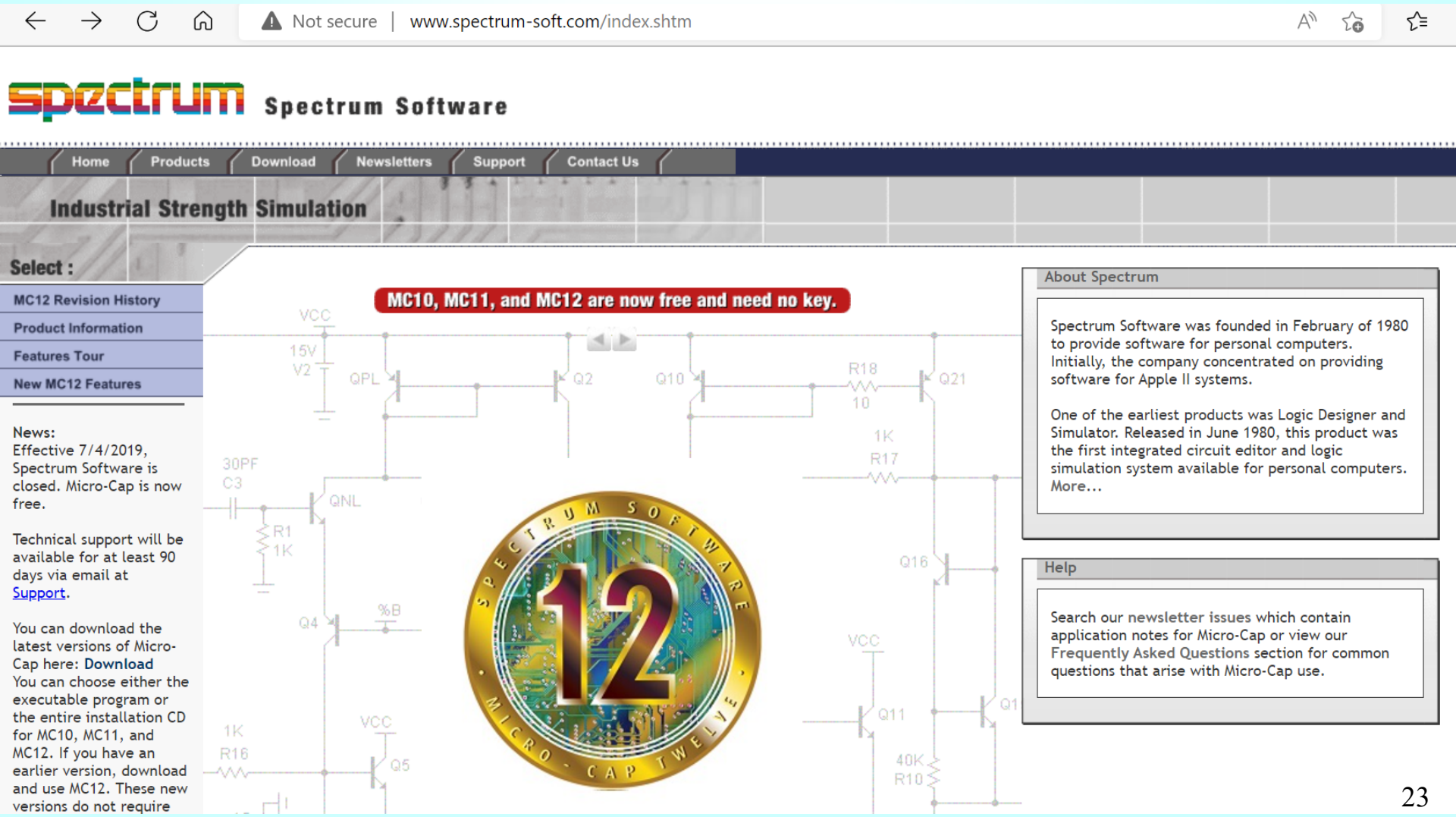
GNU Octave

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



Micro-Cap

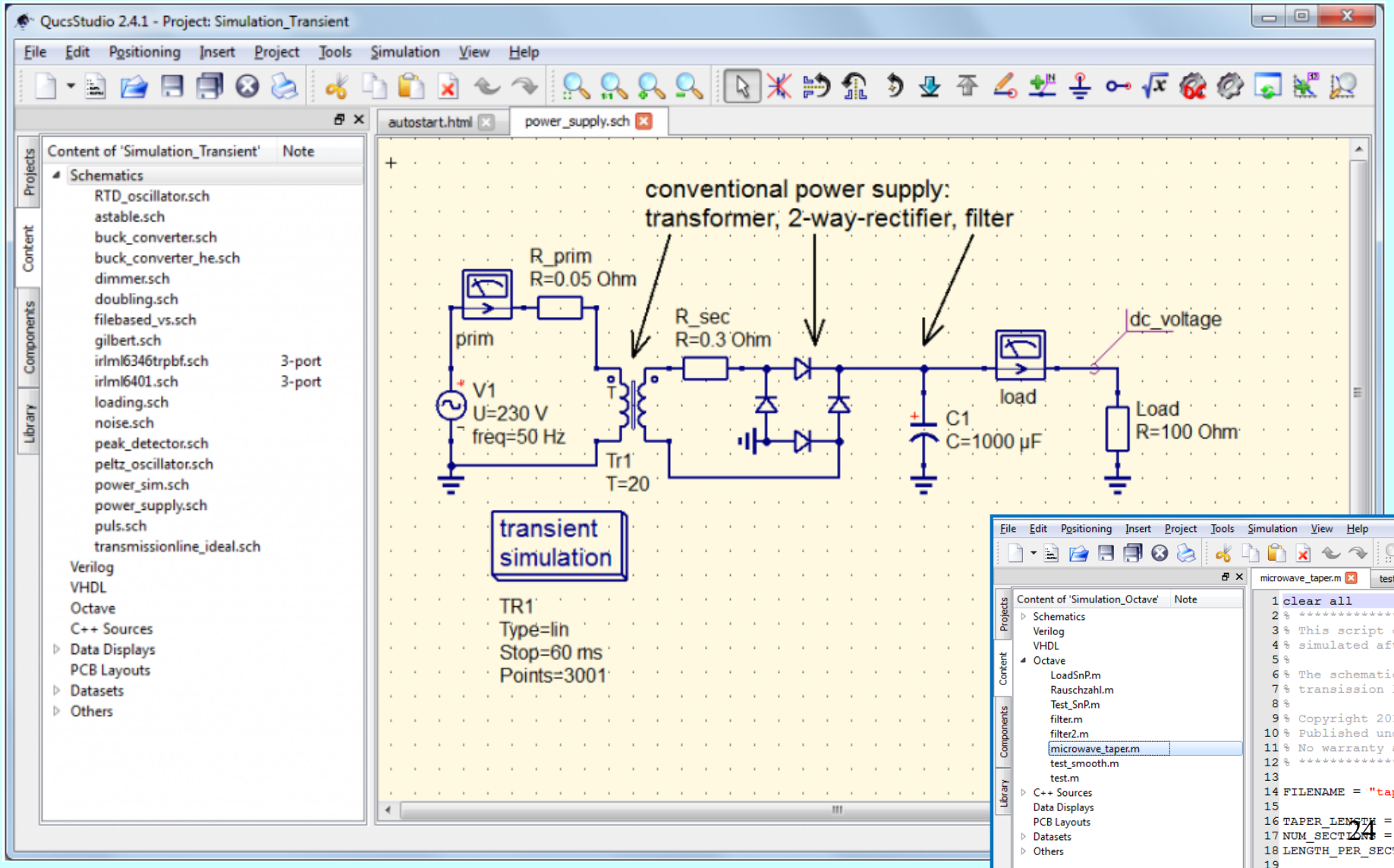
http://www.spectrum-soft.com/index.shtm



QucsStudio

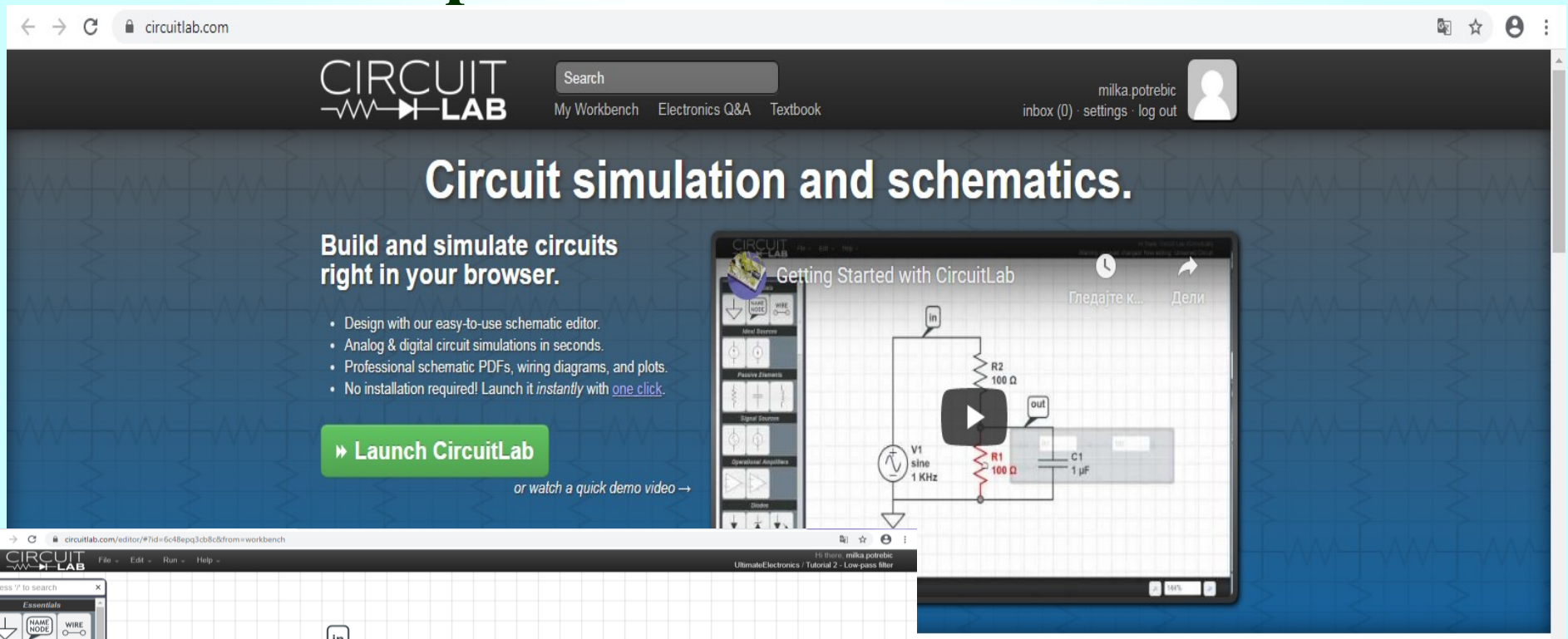
http://qucsstudio.de

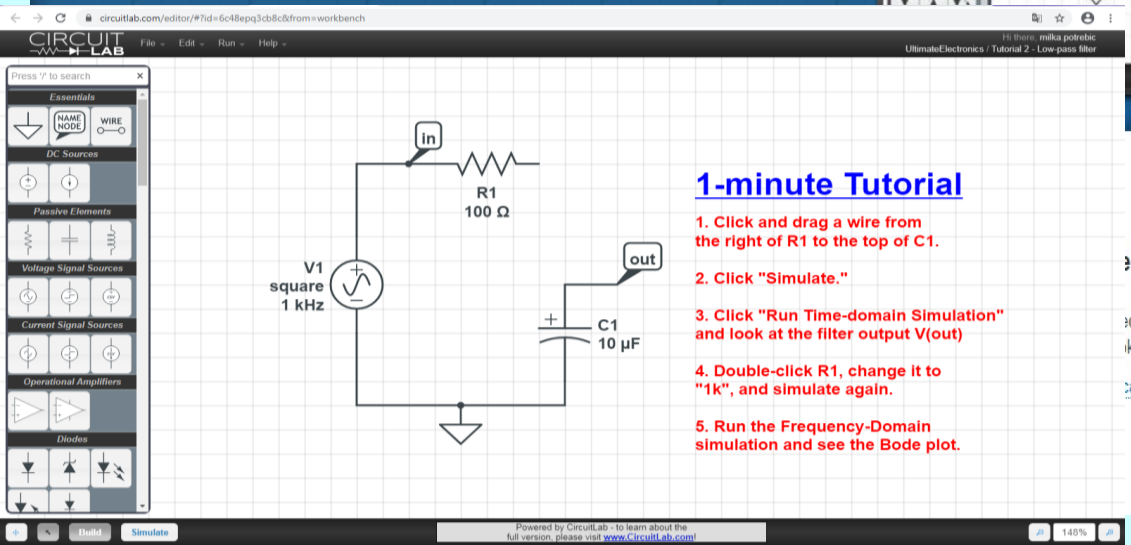
Octave engine inside!



CircuitLab

https://www.circuitlab.com/





DoCircuits Circuit Simulator

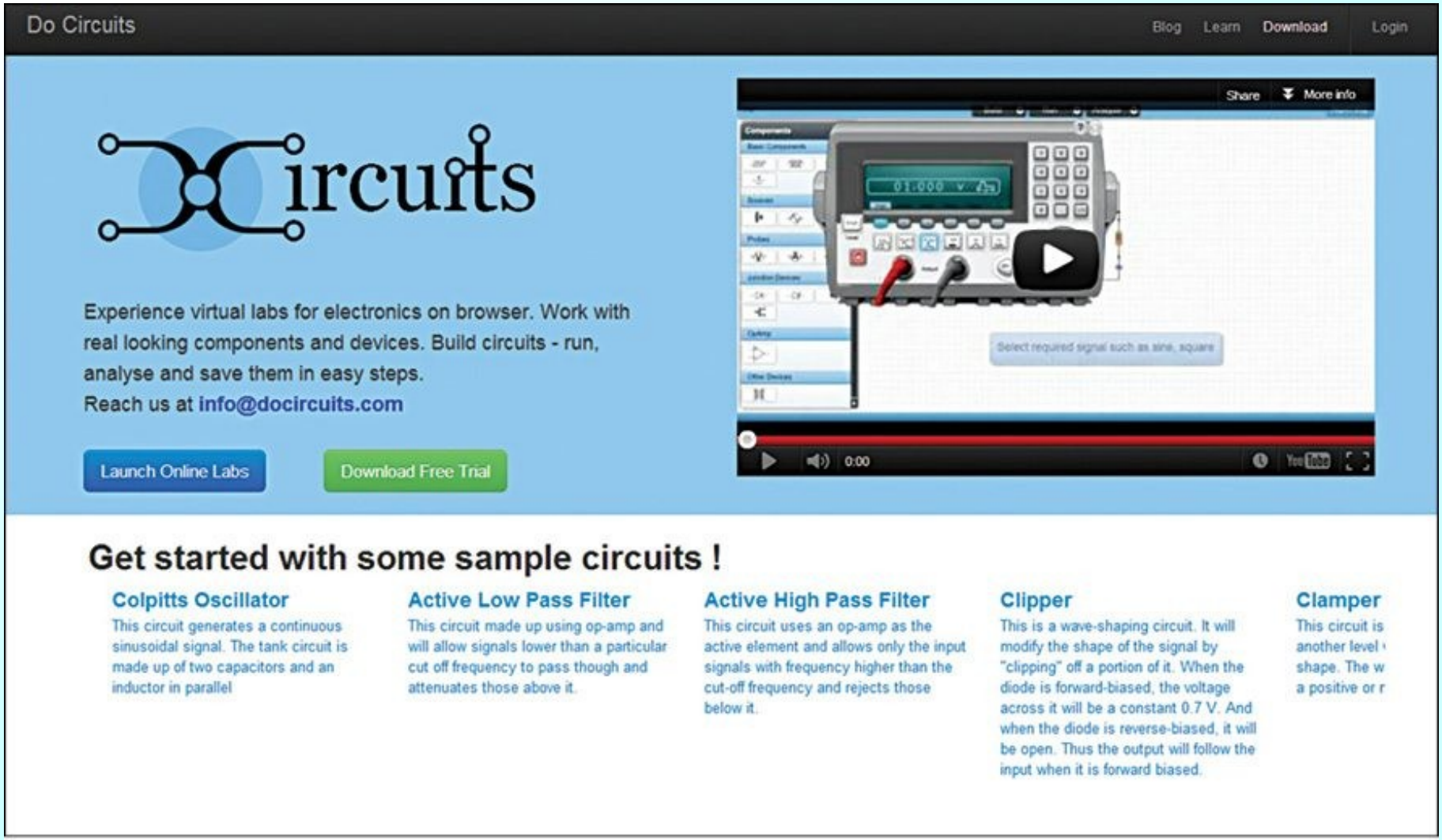


Fig. 1: DoCircuits - Home

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

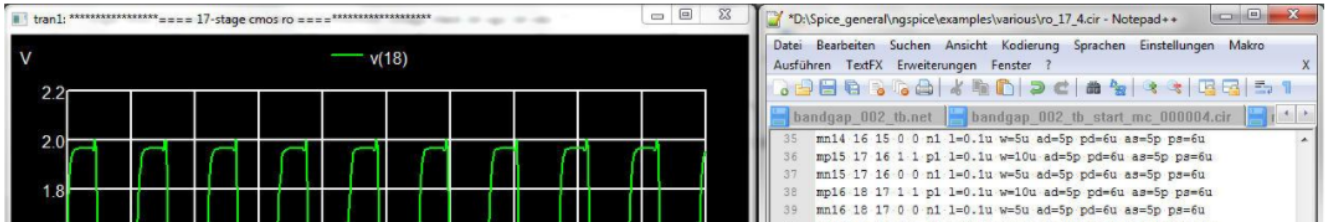
ngspice - open source spice simulator

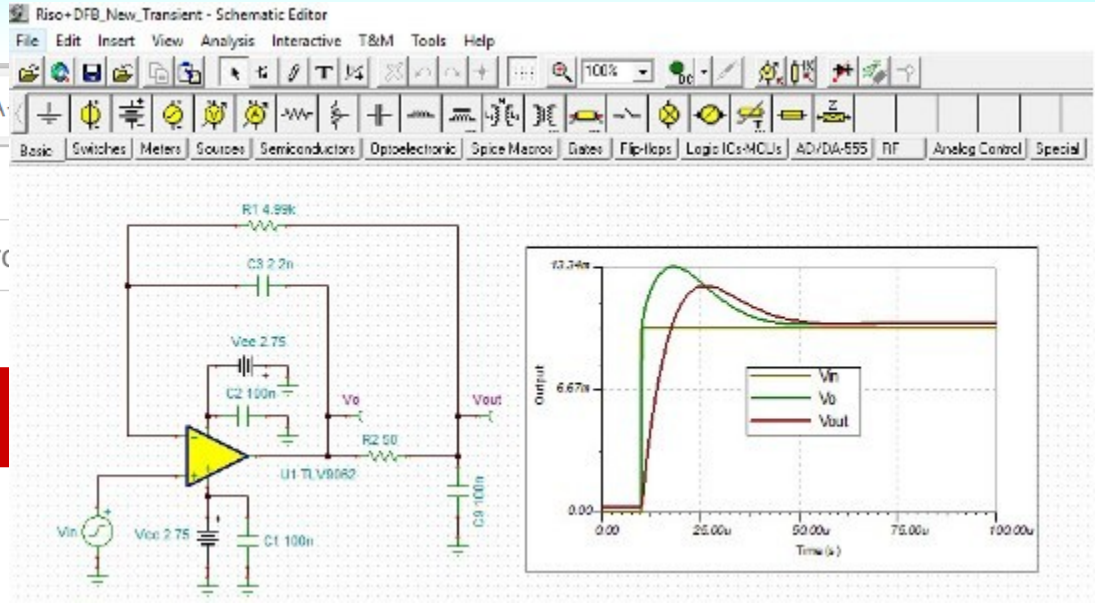
ngspice is the open source spice simulator for electric and electronic circuits.

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

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TINA-TI

SPICE-based analog simulation program

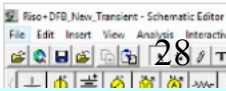
Overview | Downloads | Technical documentation | Support & training

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

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ECStudio Systems Education

2,709

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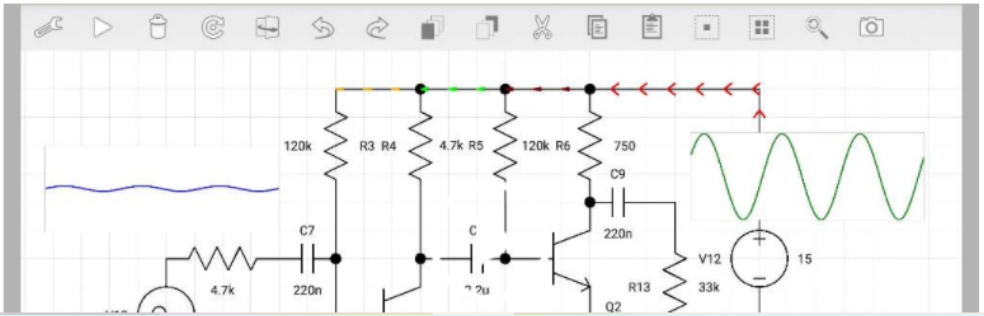

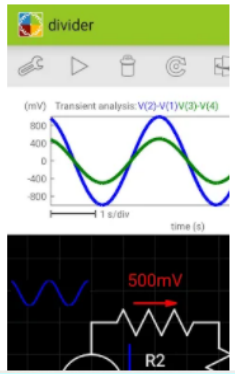

CircuitSafari SPICE Simulator

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

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Parent Guide

CircuitSafari SPICE Simulator (Early Access)

Logipipe, LLC Productivity

Everyone

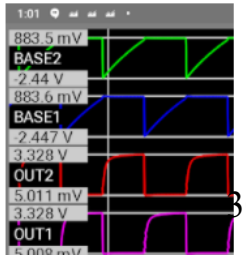
Offers in-app purchases

This app is in development. It may be unstable.

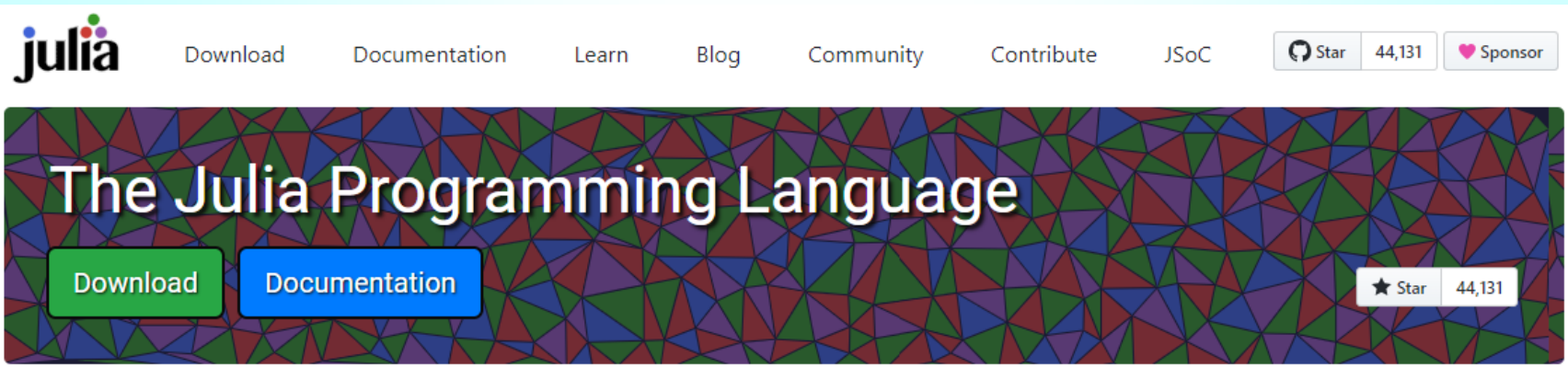
You don't have any devices

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

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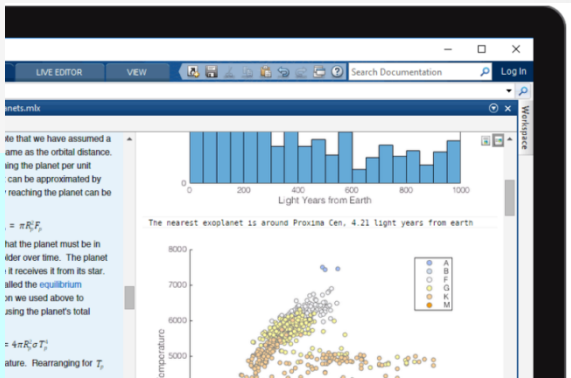
MATLAB® combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. It includes the Live Editor for creating scripts that combine code, output, and formatted text in an executable notebook.

Design AI models and AI-driven systems



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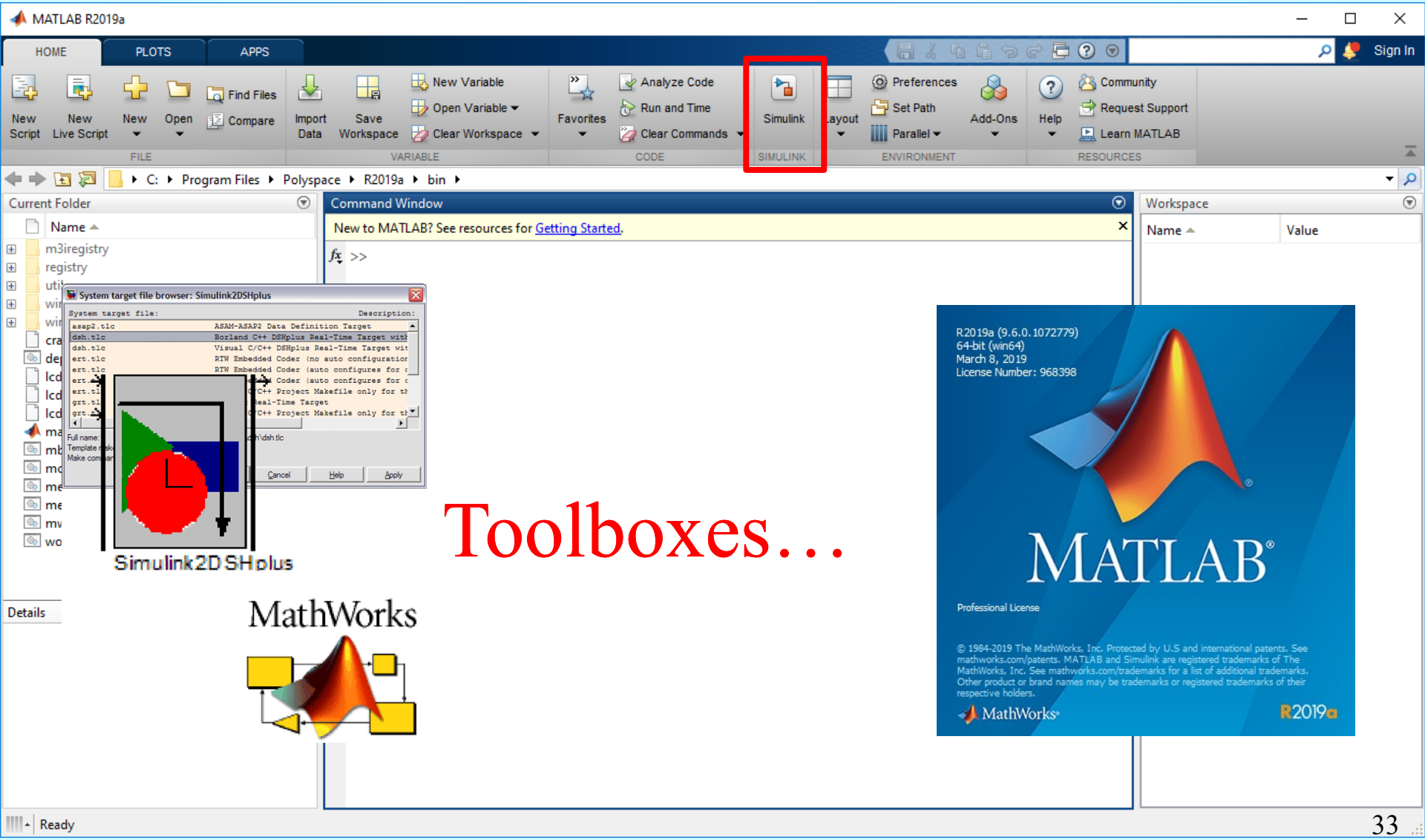
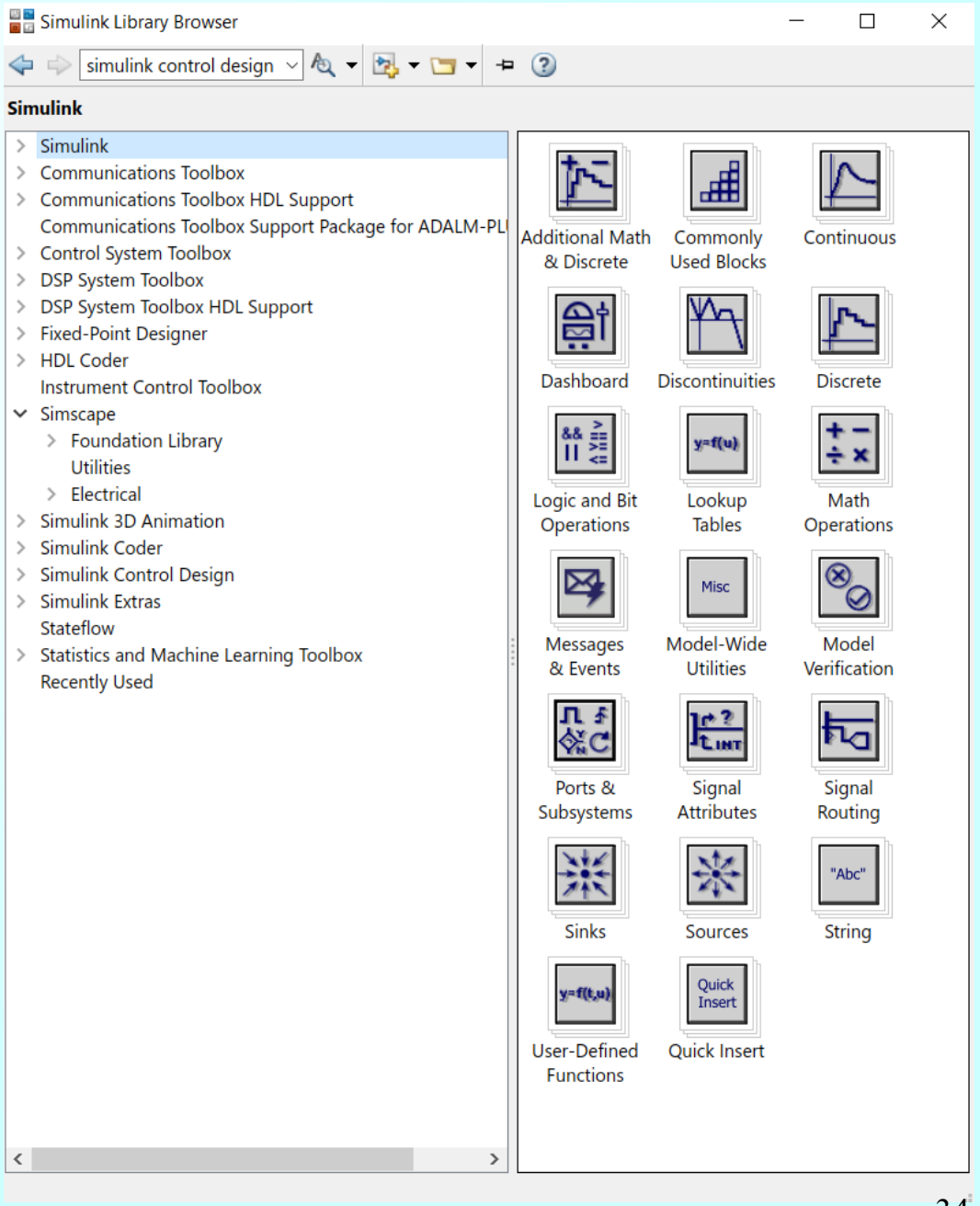


Toolboxes…

MATLAB Simulink

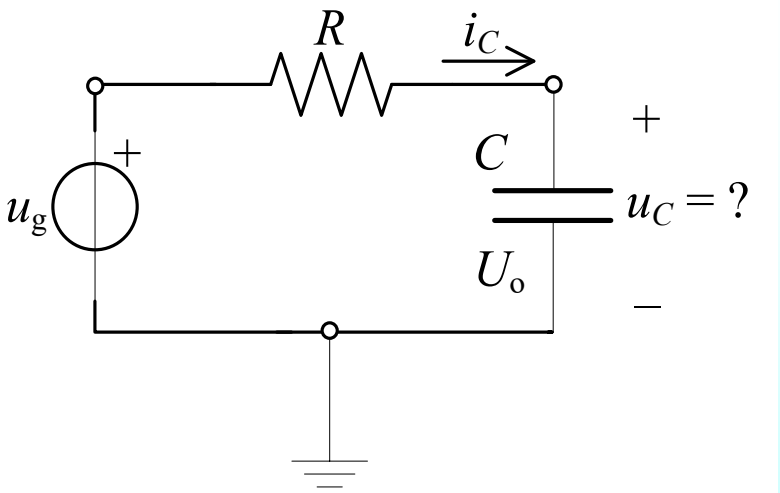
- Алатка за нумеричку анализу математичких модела
- Систем се дефинише графички, уметањем блокова и њиховим повезивањем у мрежу



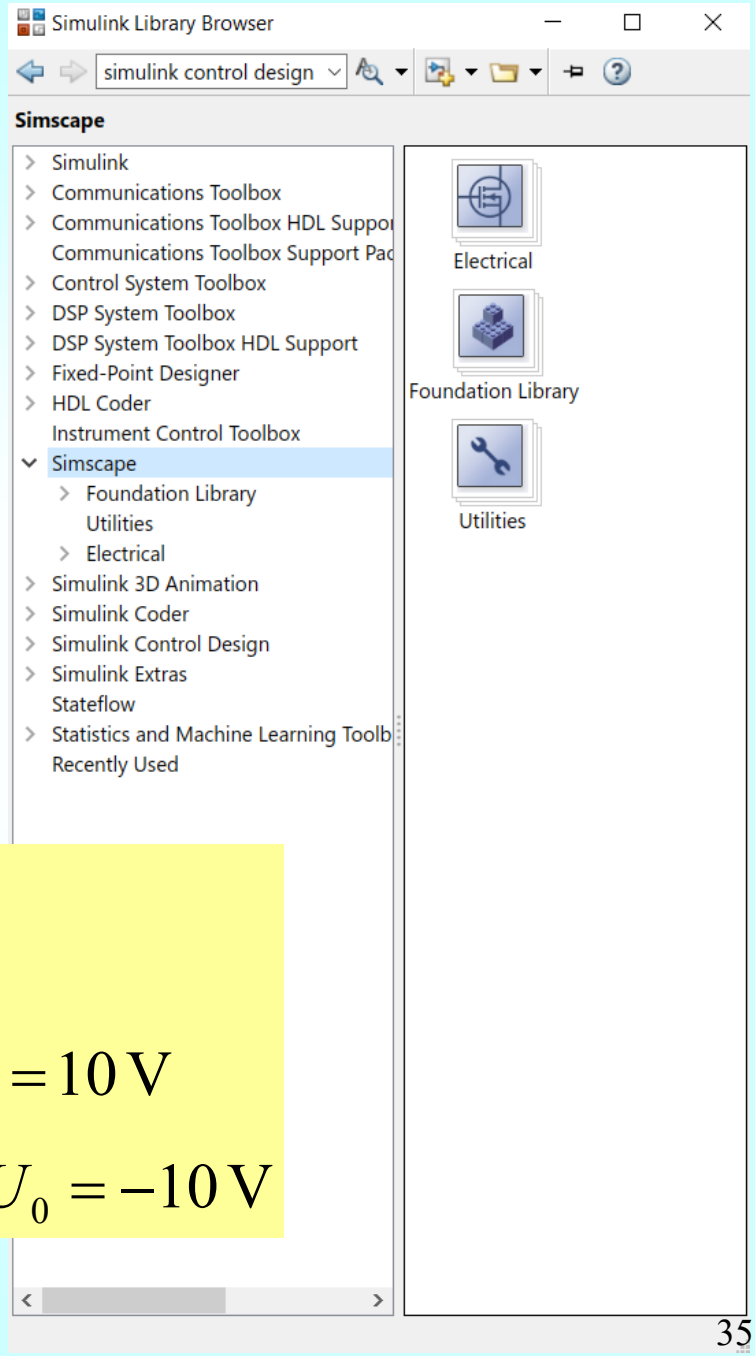
Simulink > Simscape

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

коло је образовано у тренутку $t_0 = 0$

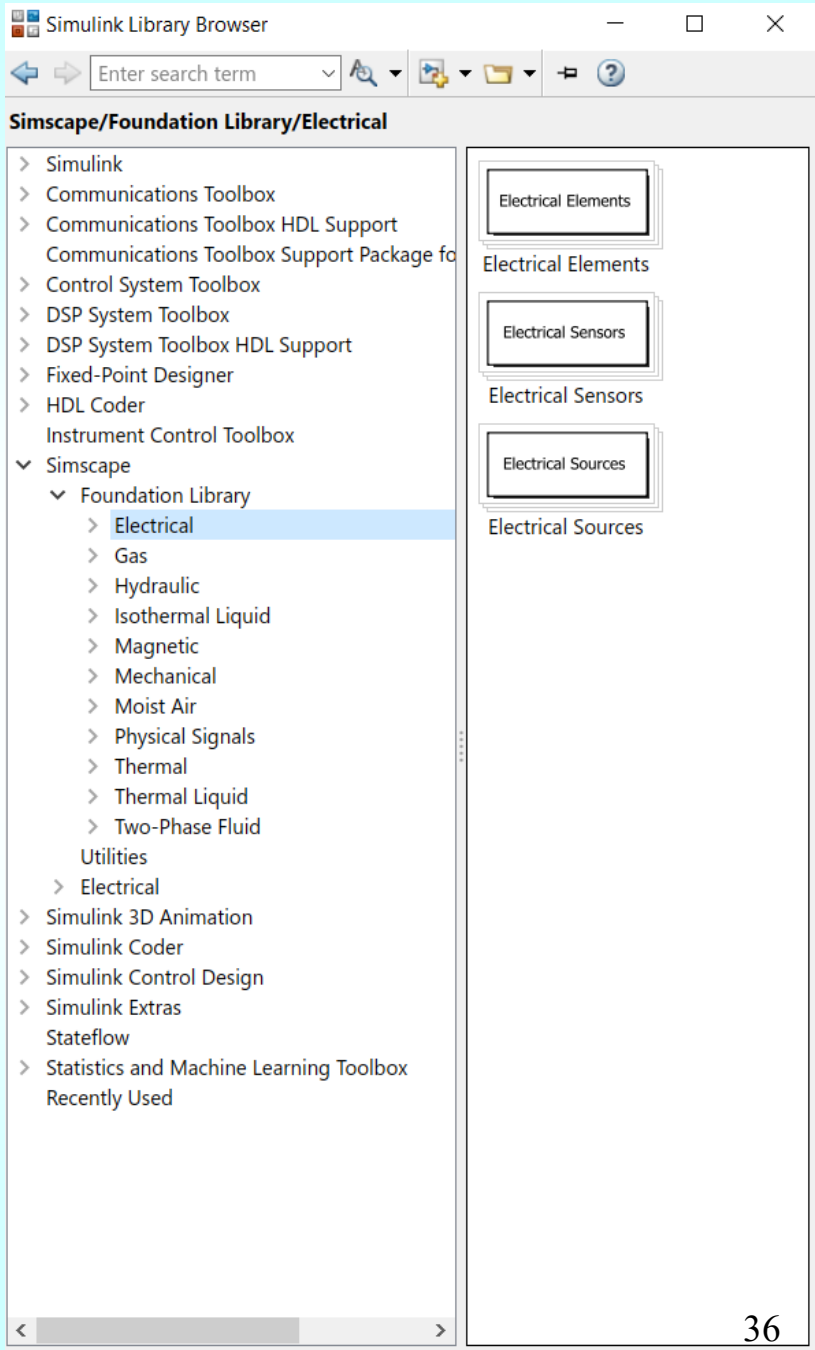


$$R = 1\,\mathrm{k\Omega}$$
$$C = 1\,\mu\mathrm{F}$$
$$u_g(t) = U = 10\,\mathrm{V}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$



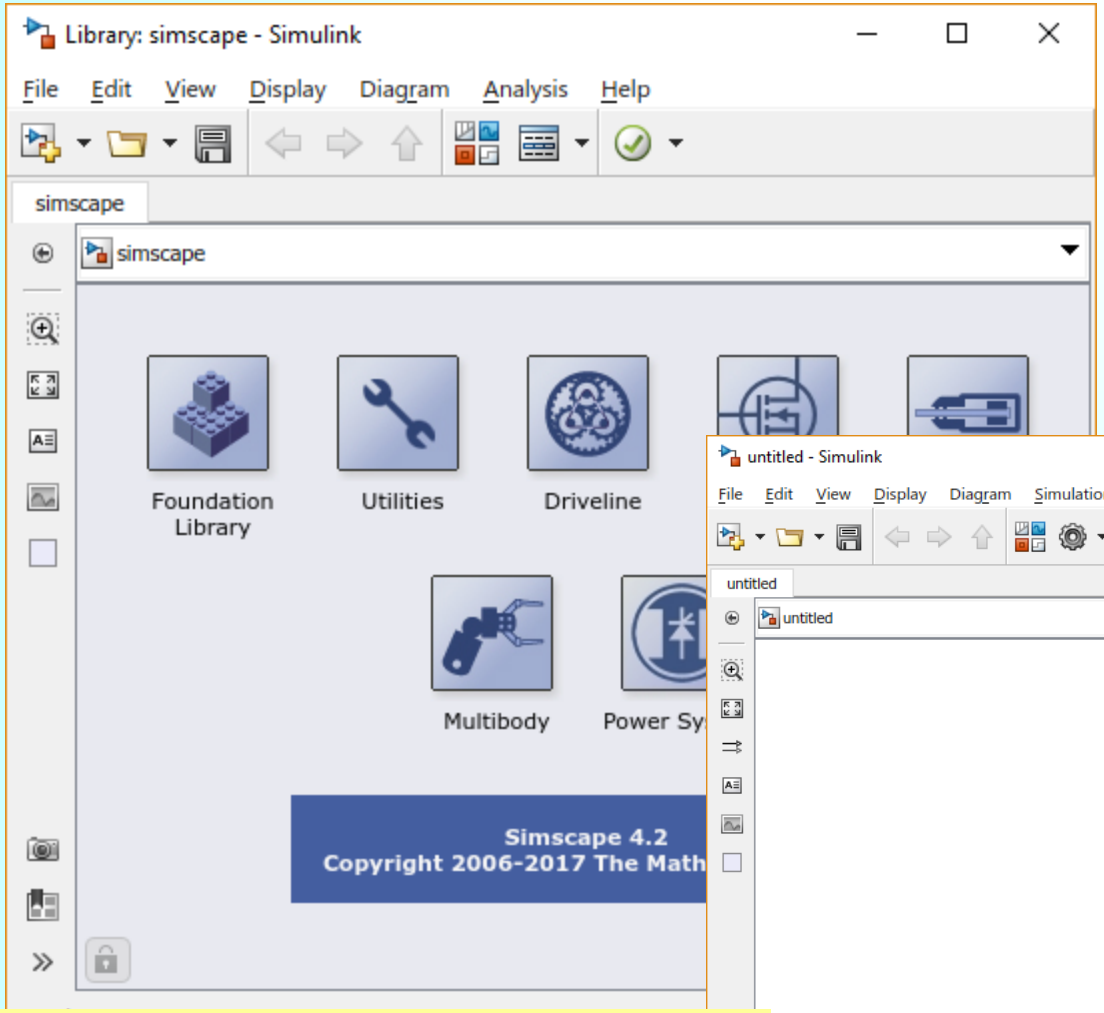
Simulink > Simscape > Foundation Library > Electrical

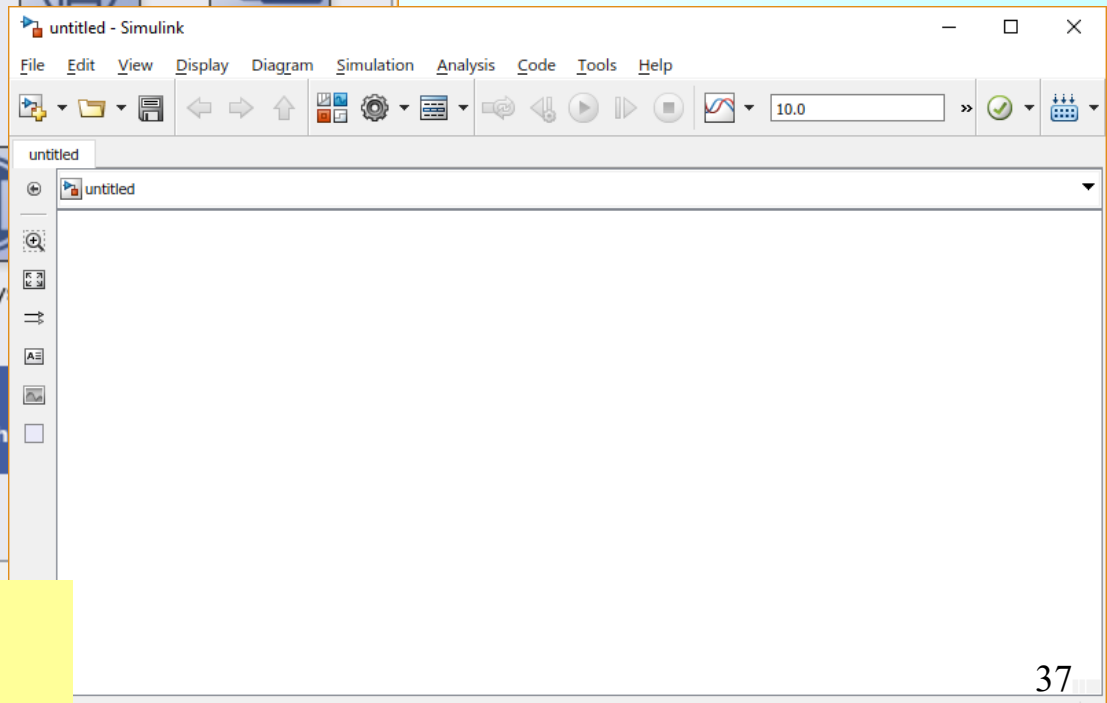
- Симулација линеарних и нелинеатних електричних кола



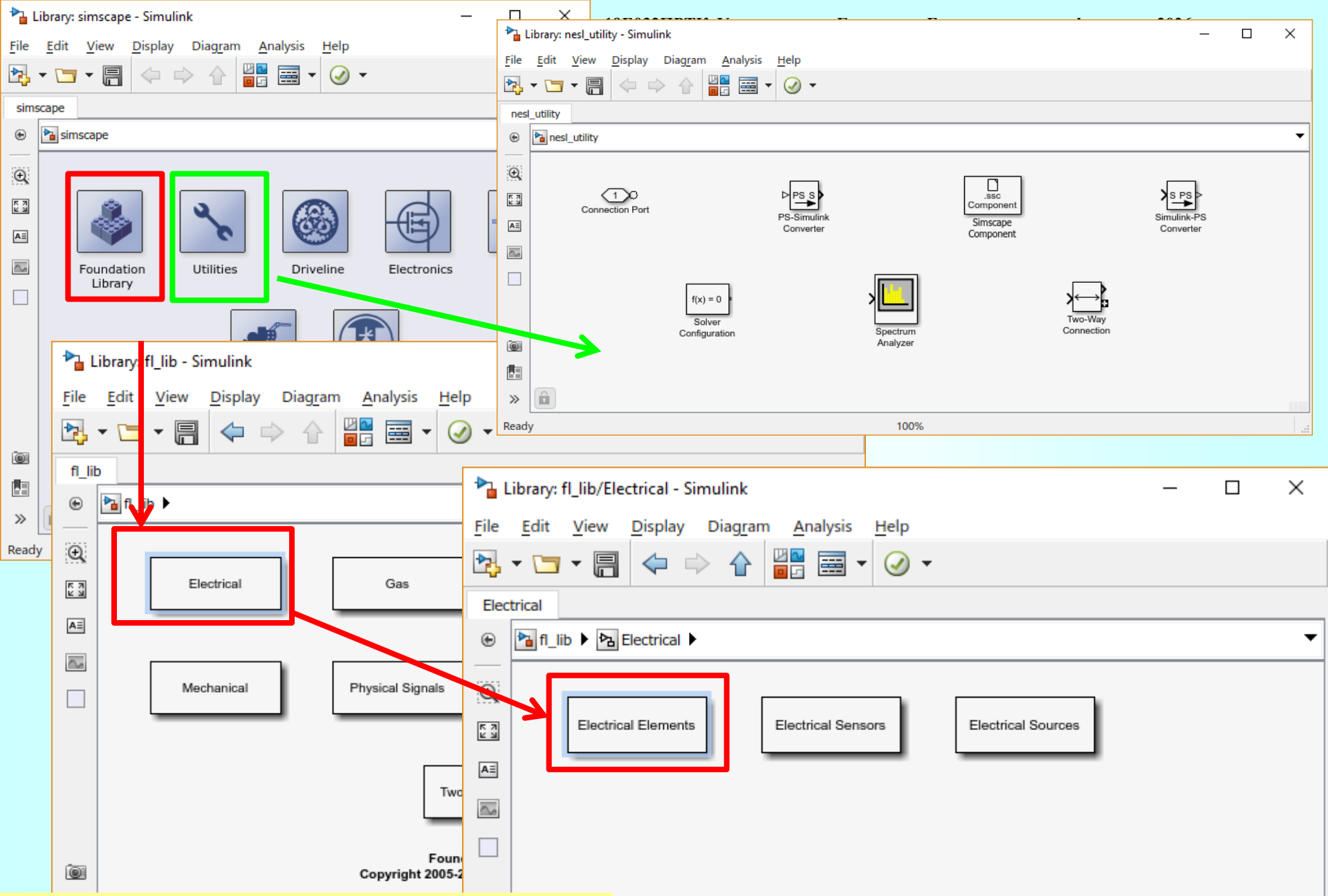
MATLAB > Simscape > Foundation Library, Utilities

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



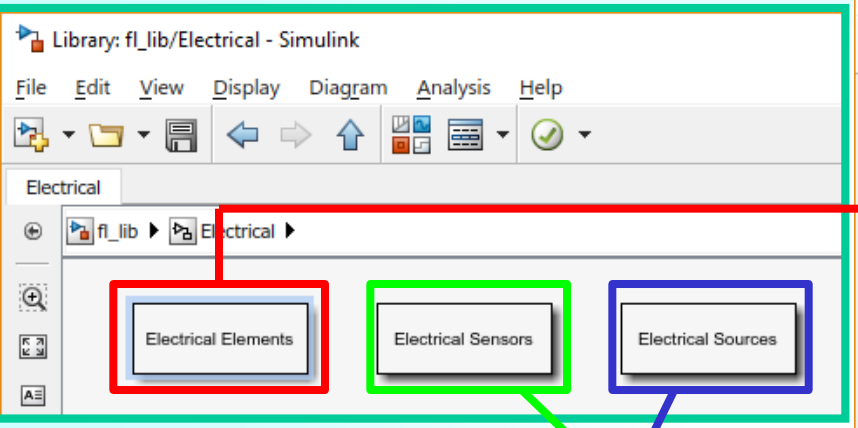


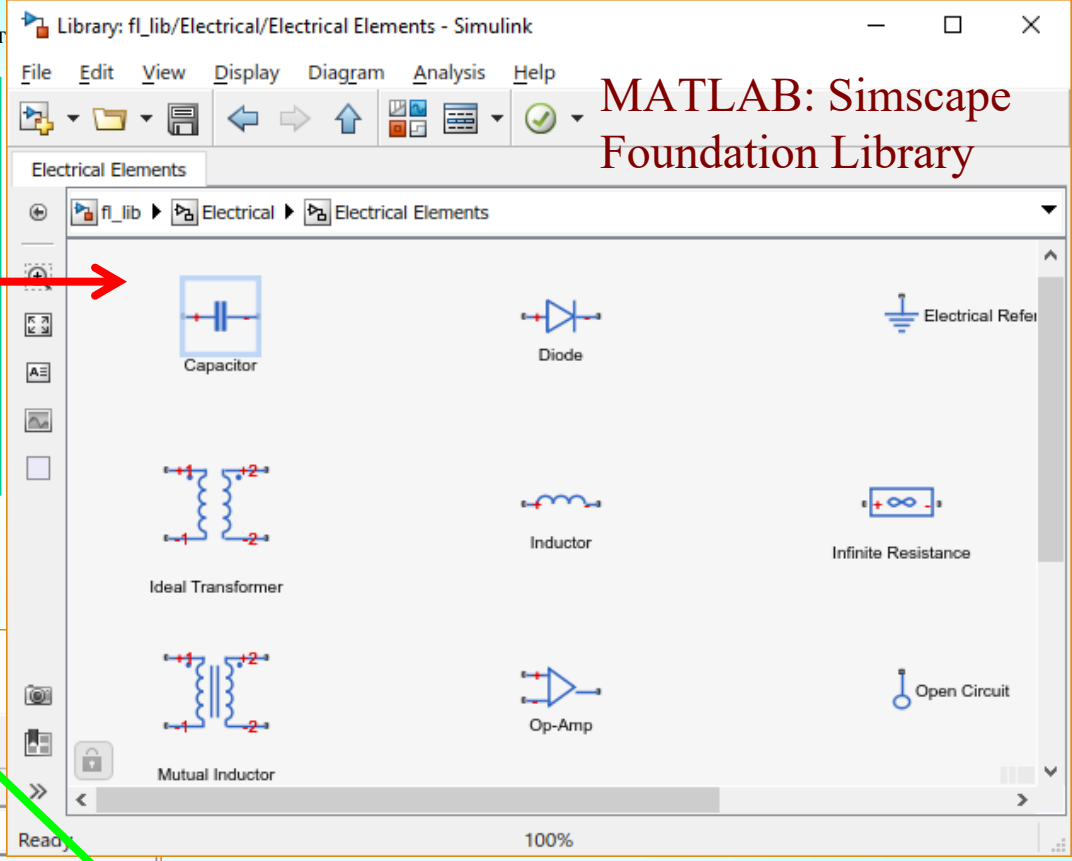
MATLAB > Simscape > Foundation Library, Utilities

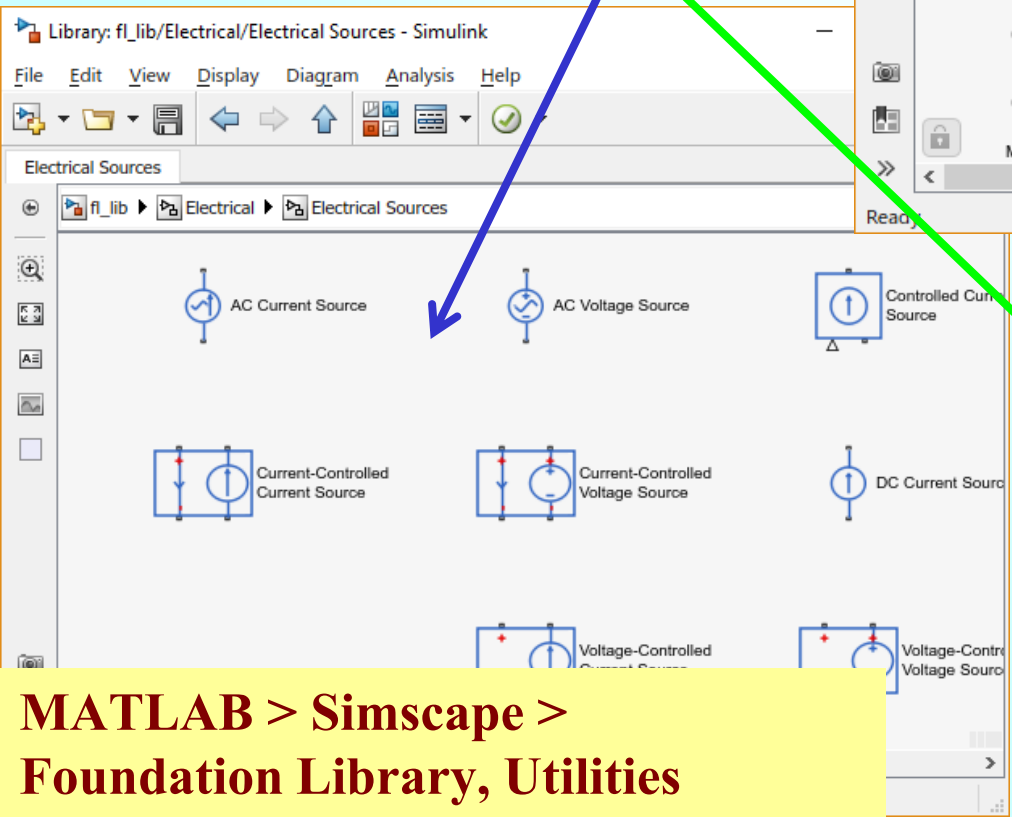


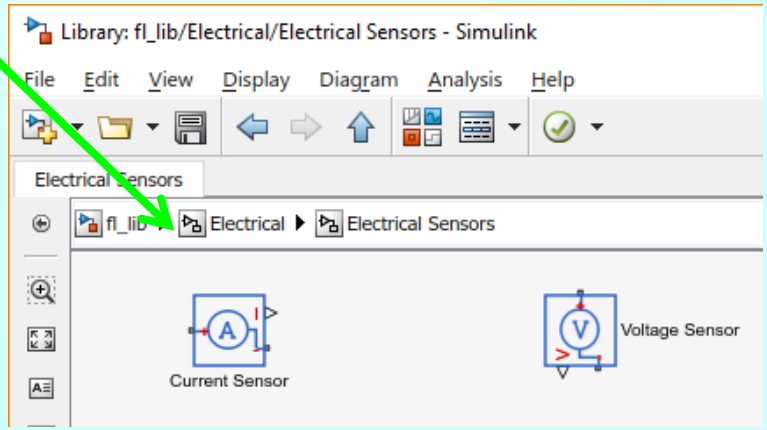
MATLAB > Simscape > Foundation Library, Utilities

MATLAB: Simscape Foundation Library



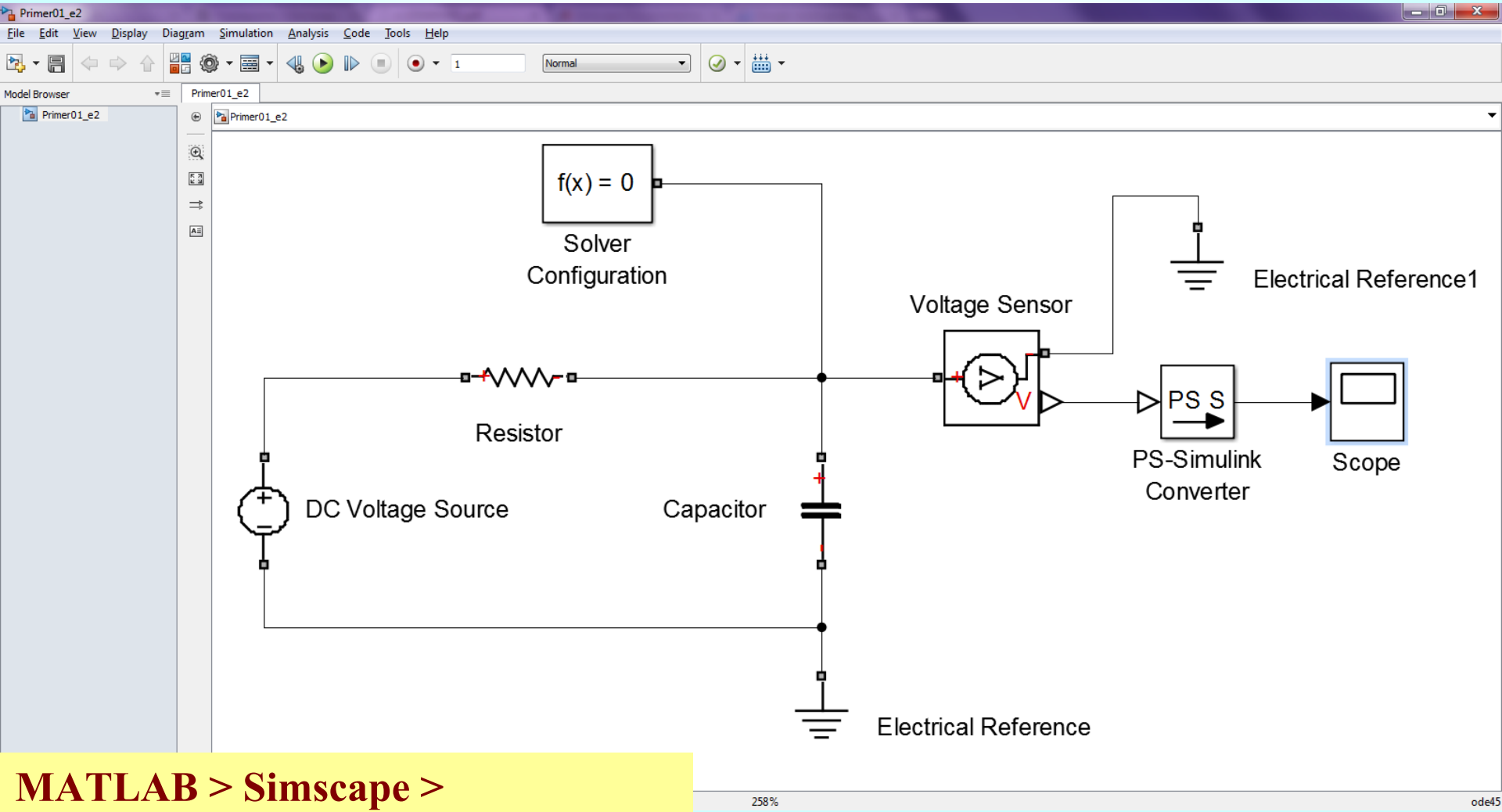




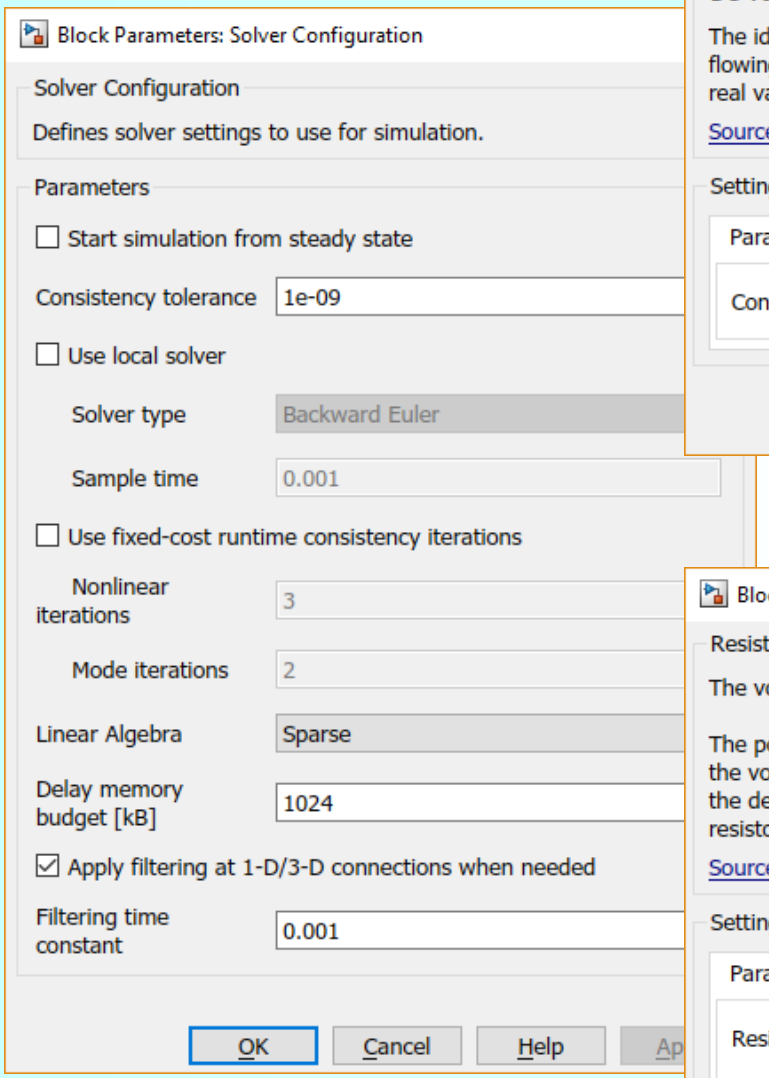


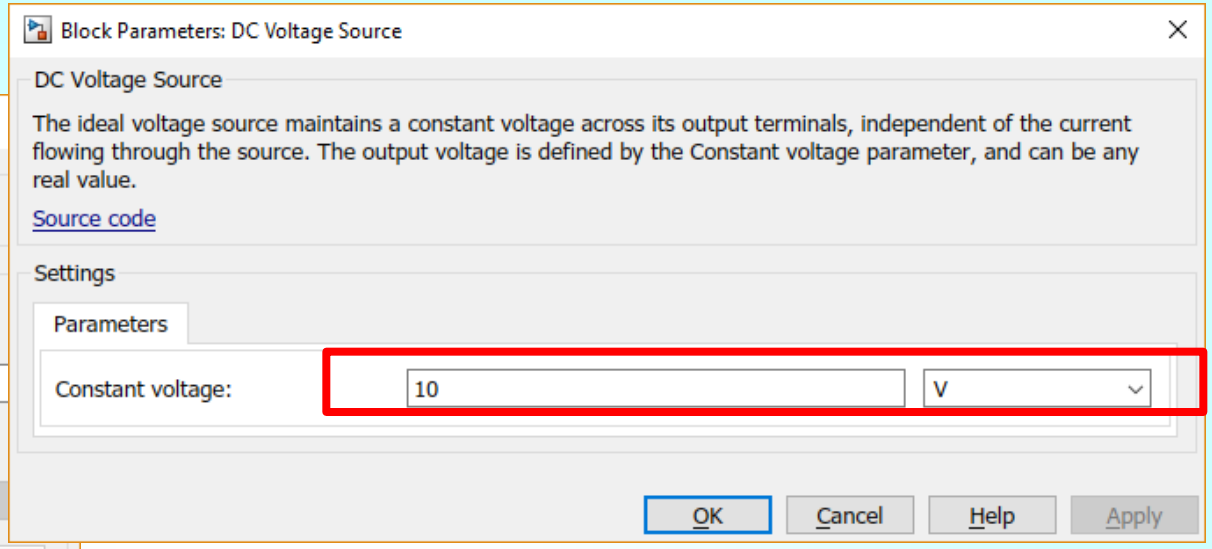
MATLAB > Simscape > Foundation Library, Utilities

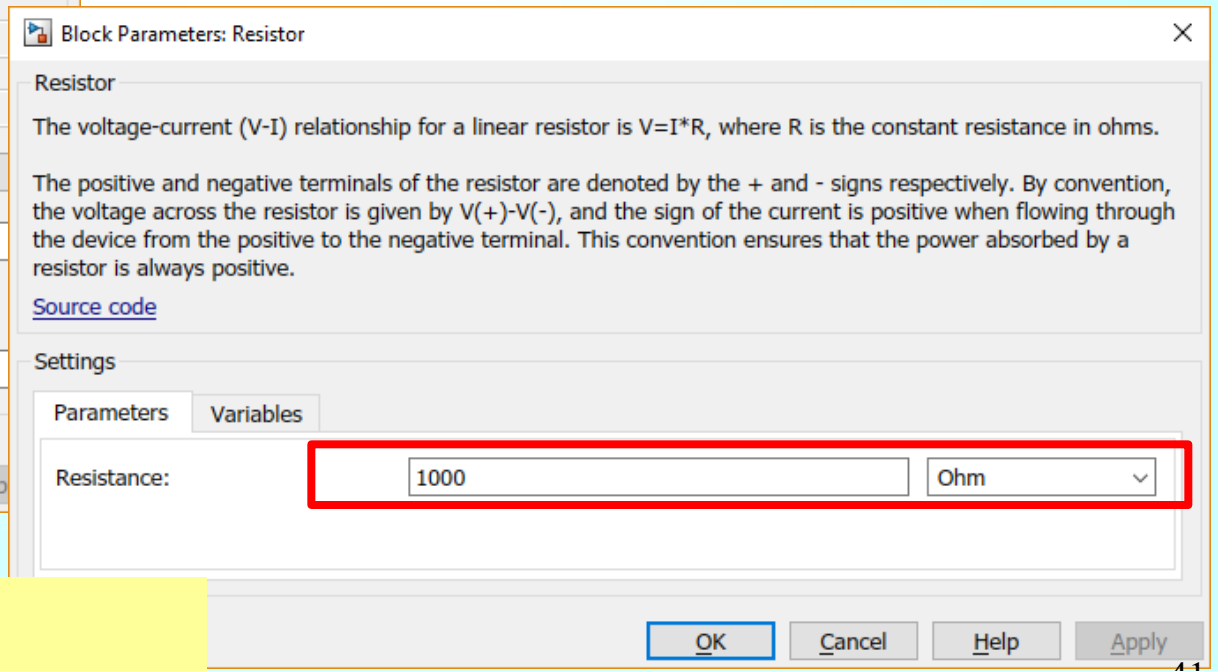
Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке



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

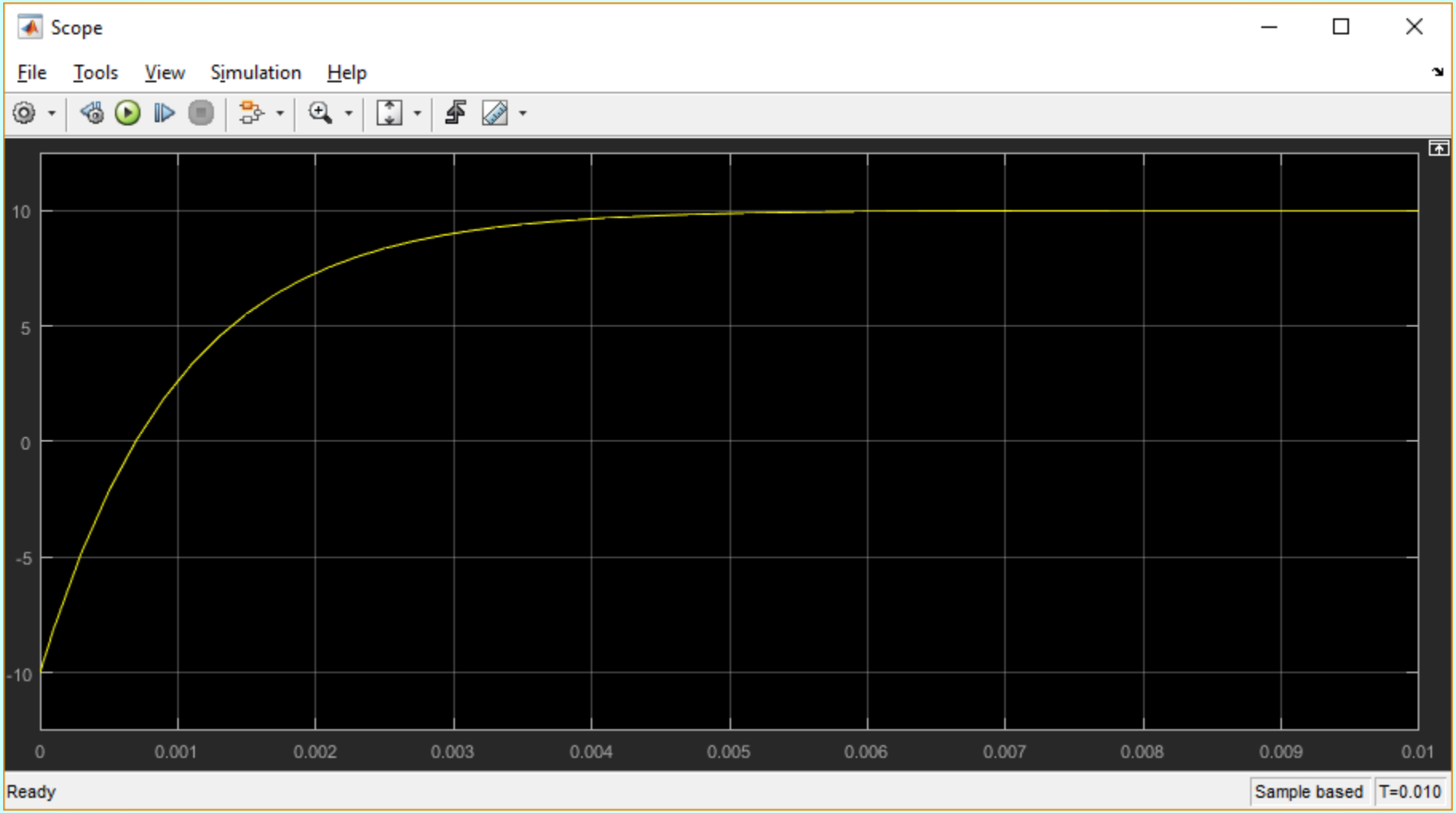
Parameters | Variables

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

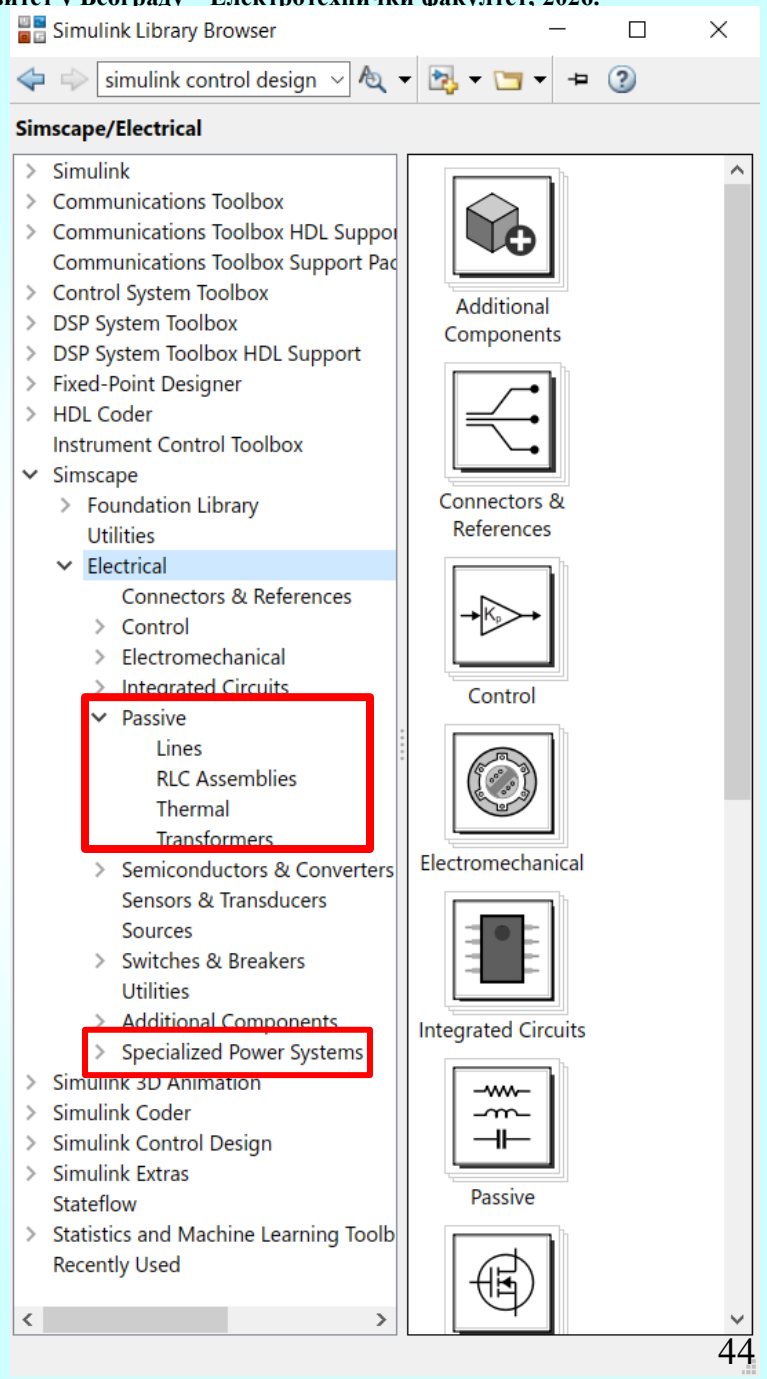
Одређивање одзива...



MATLAB > Simscape > Foundation Library, Utilities

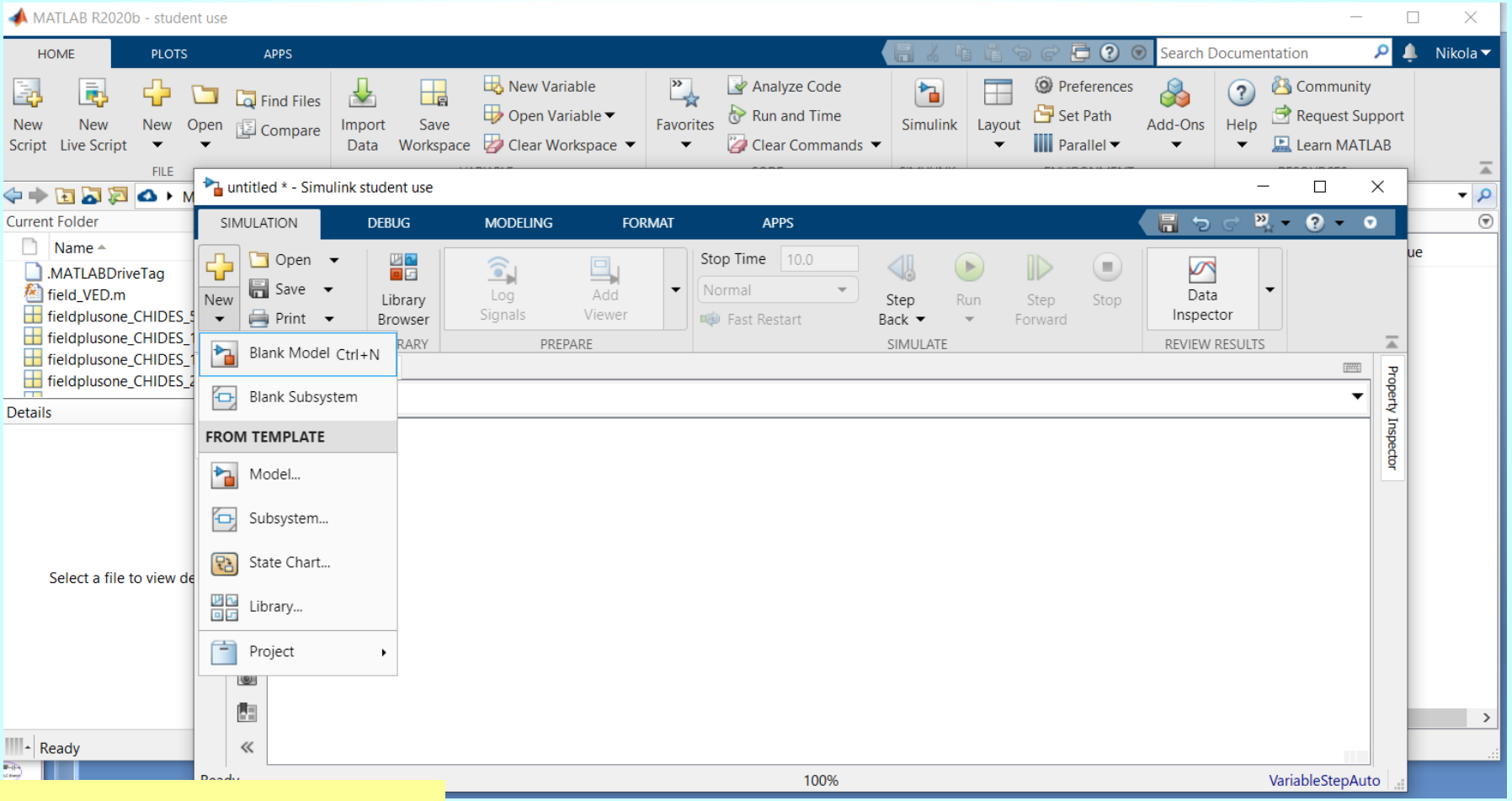
Simulink > Simscape > Electrical

- 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

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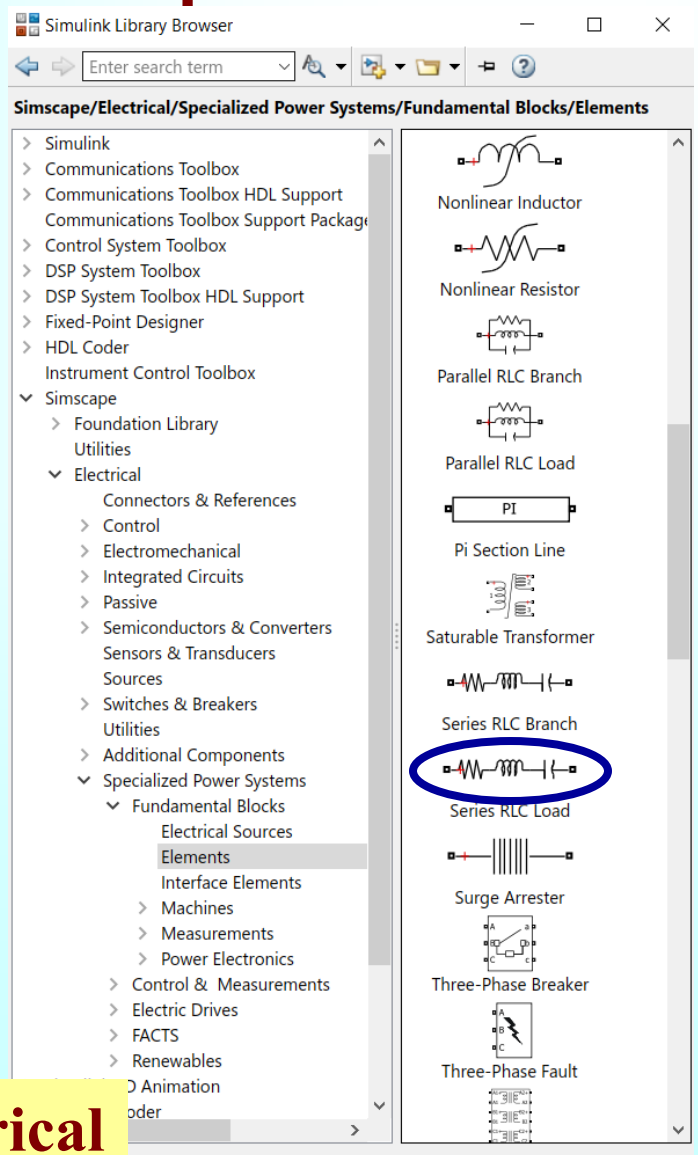
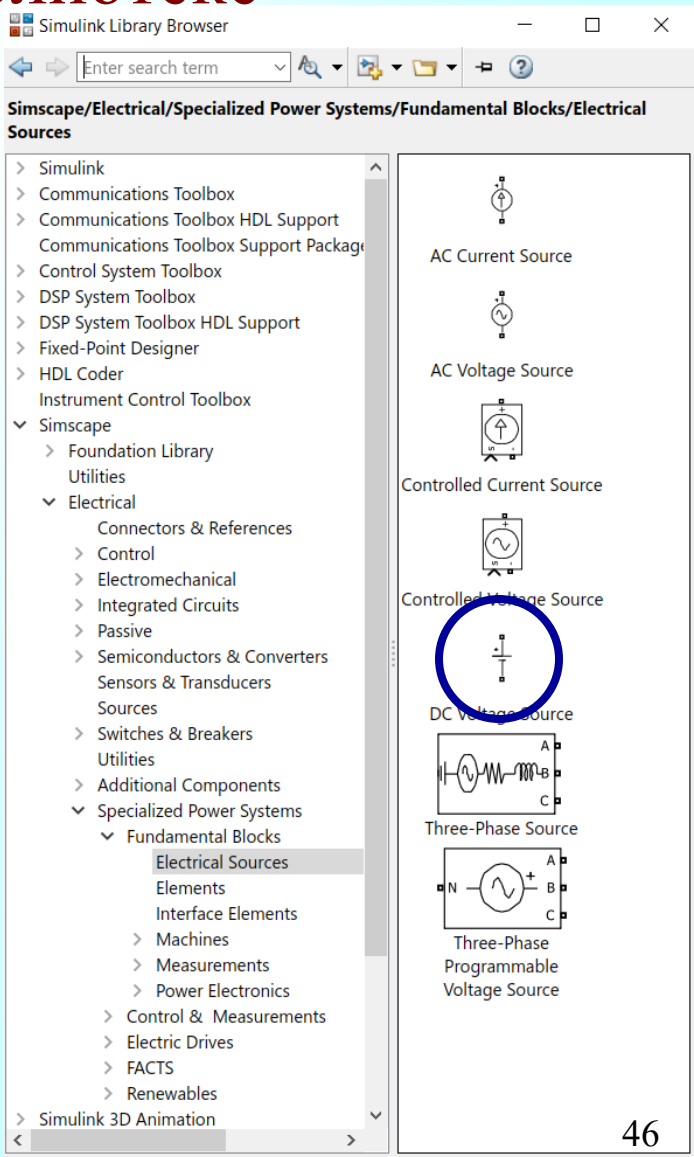
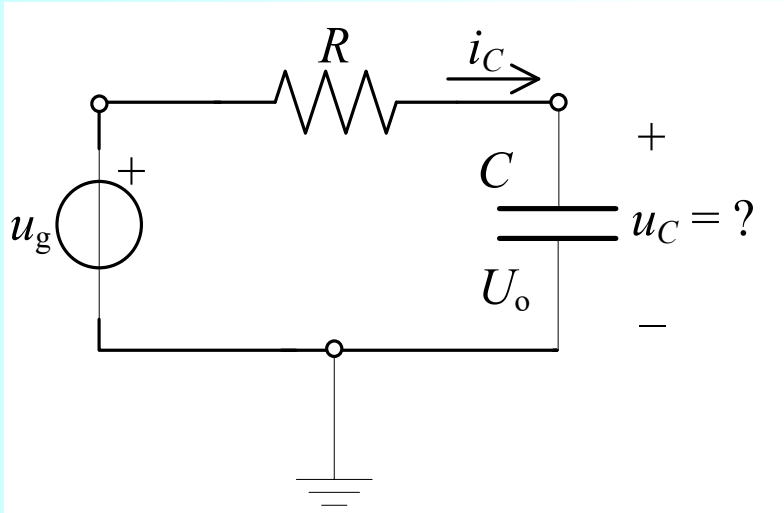


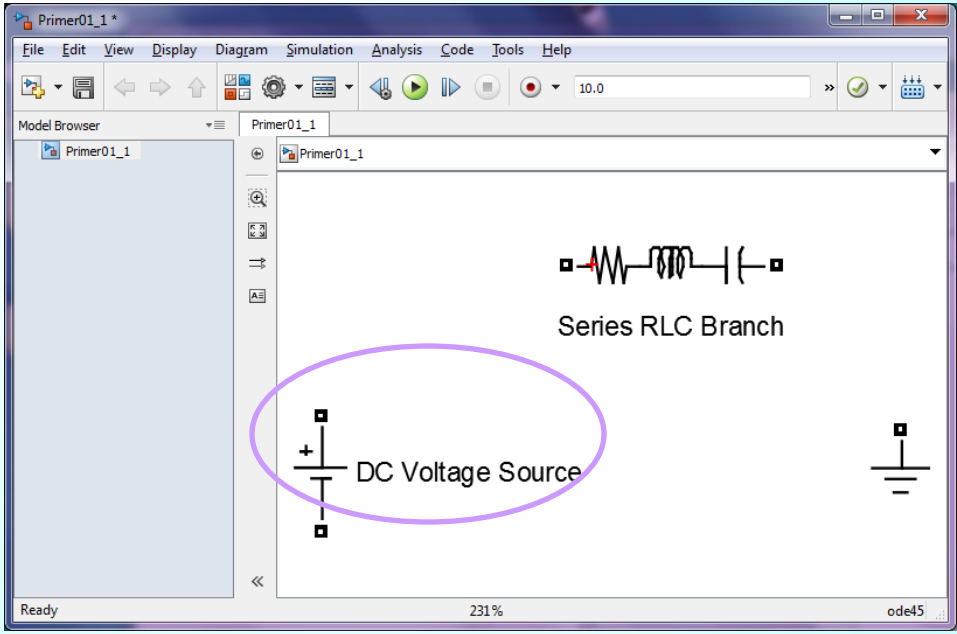


Simscape > Electrical

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

коло је образовано у тренутку $t_0 = 0$



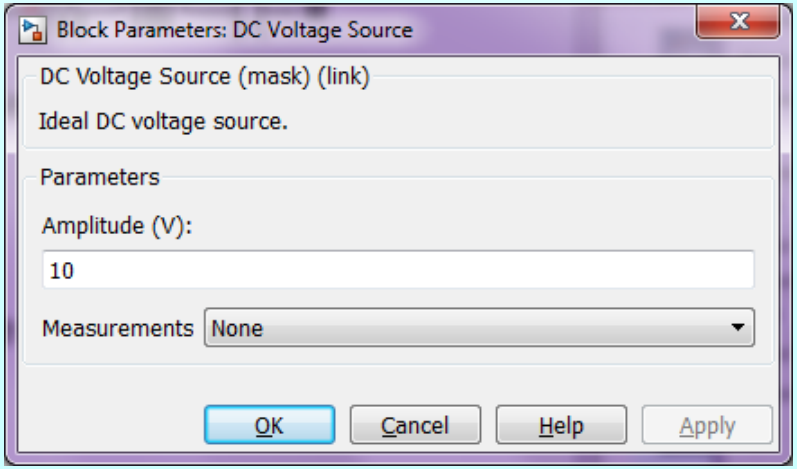


$R = 1\,\mathrm{k\Omega}$

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

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

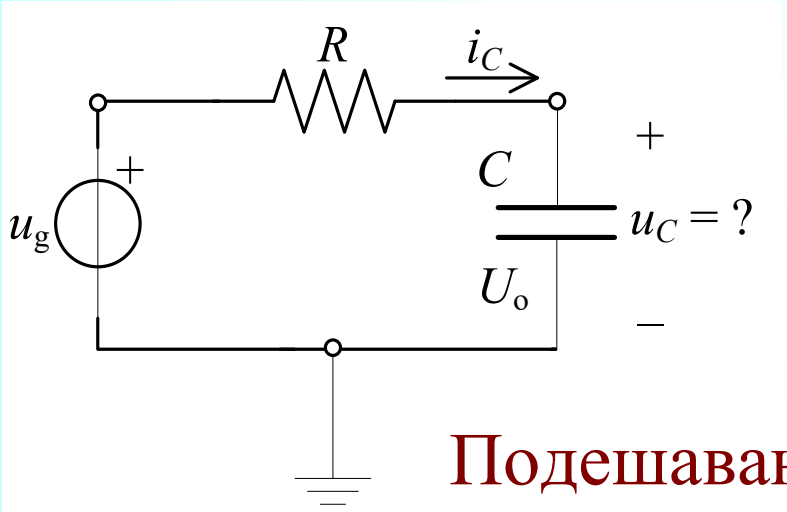
$u(t_0^-) = U_0 = -10\,\mathrm{V}$



Simscape > Electrical

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

коло је образовано у тренутку $t_0 = 0$



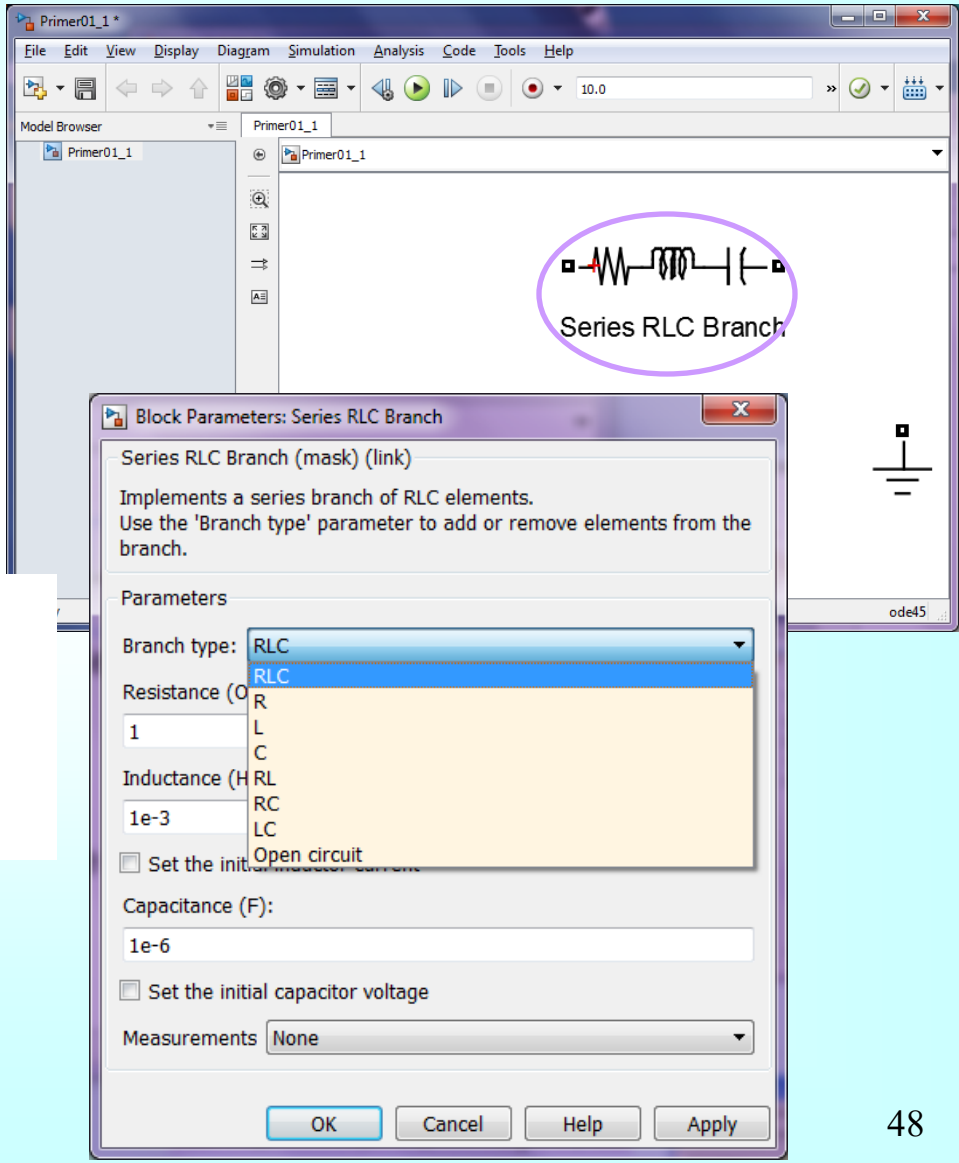
$R = 1\,\mathrm{k\Omega}$

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

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

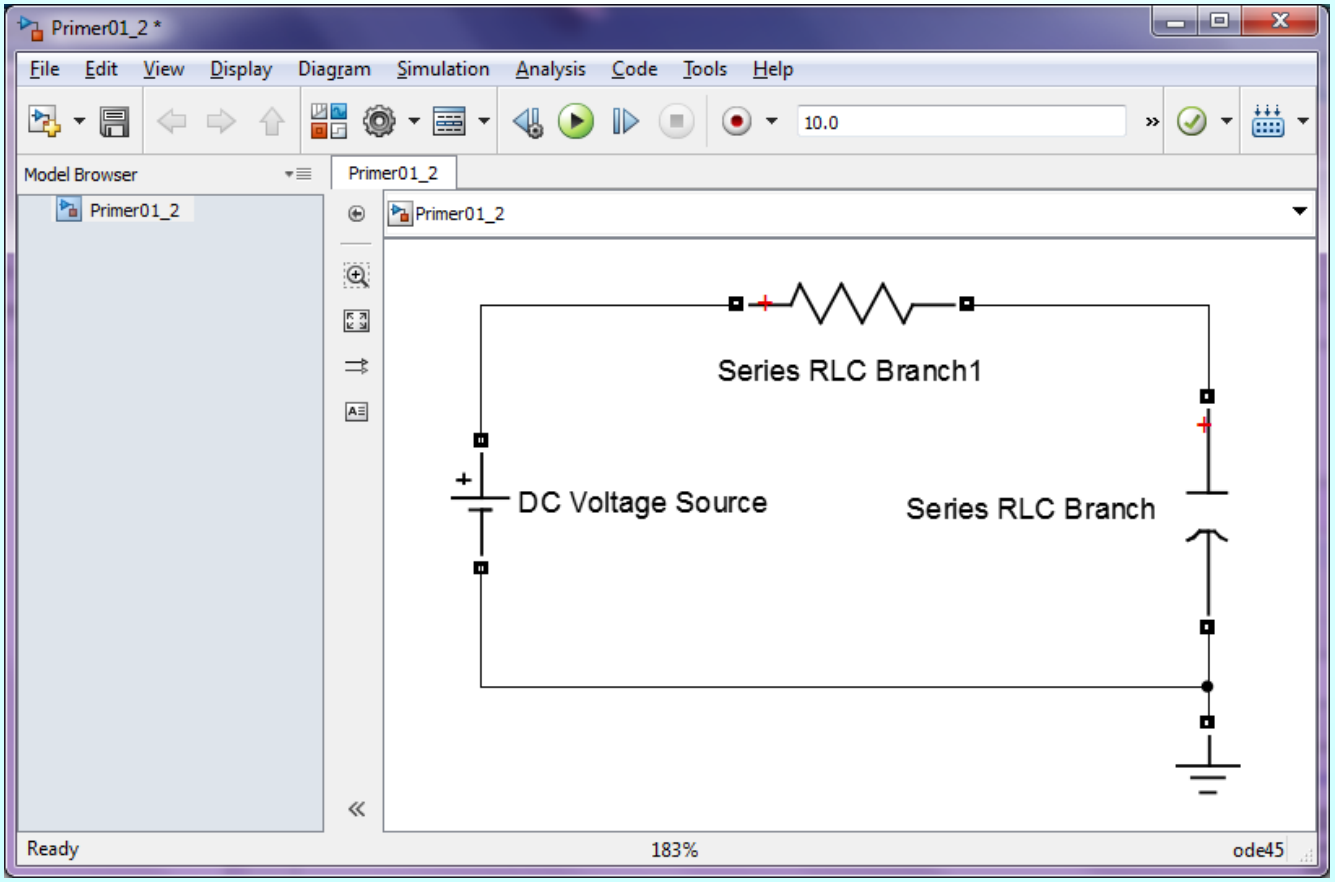
$u(t_0^-) = U_0 = -10\,\mathrm{V}$

Подешавање параметара симулације



Simscape > Electrical

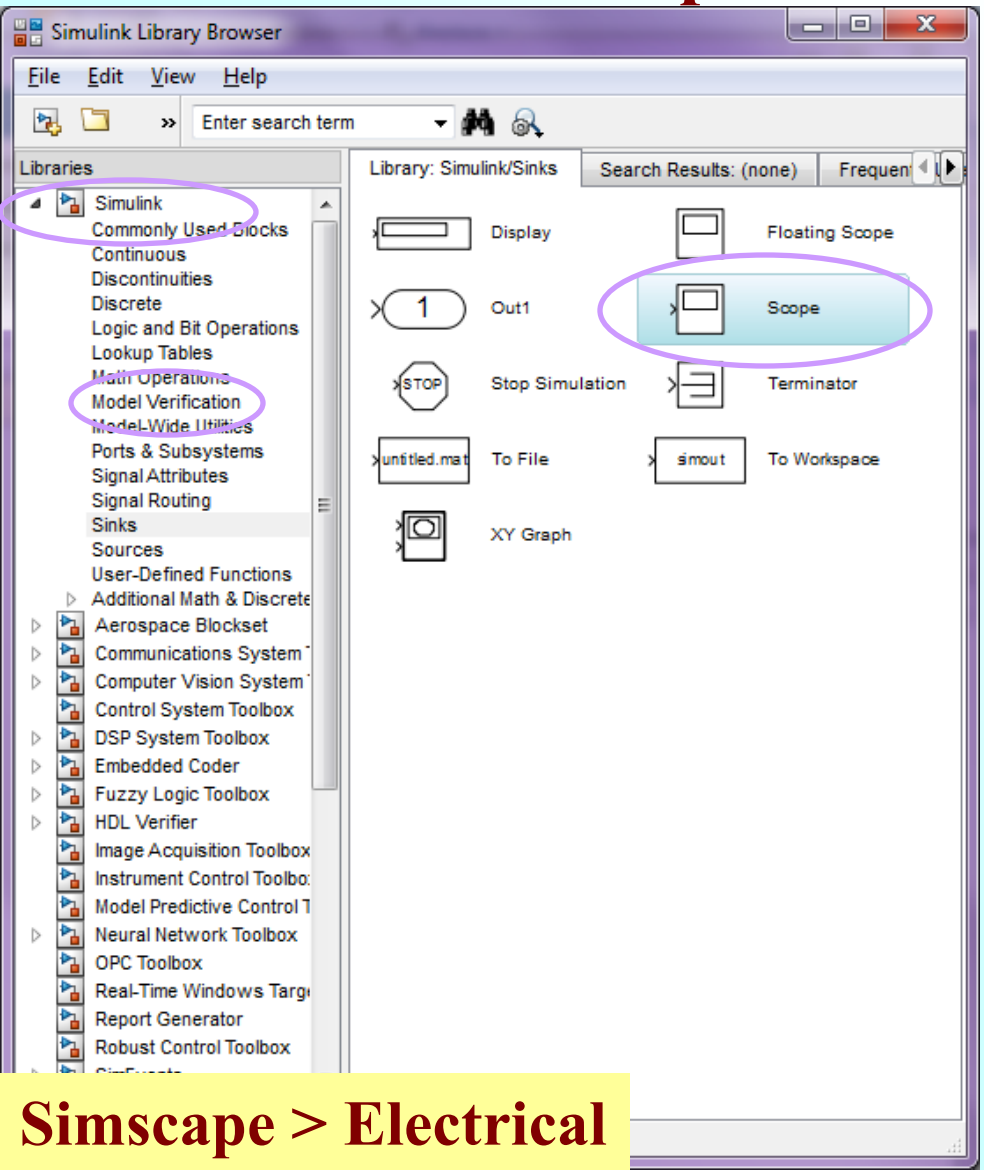
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

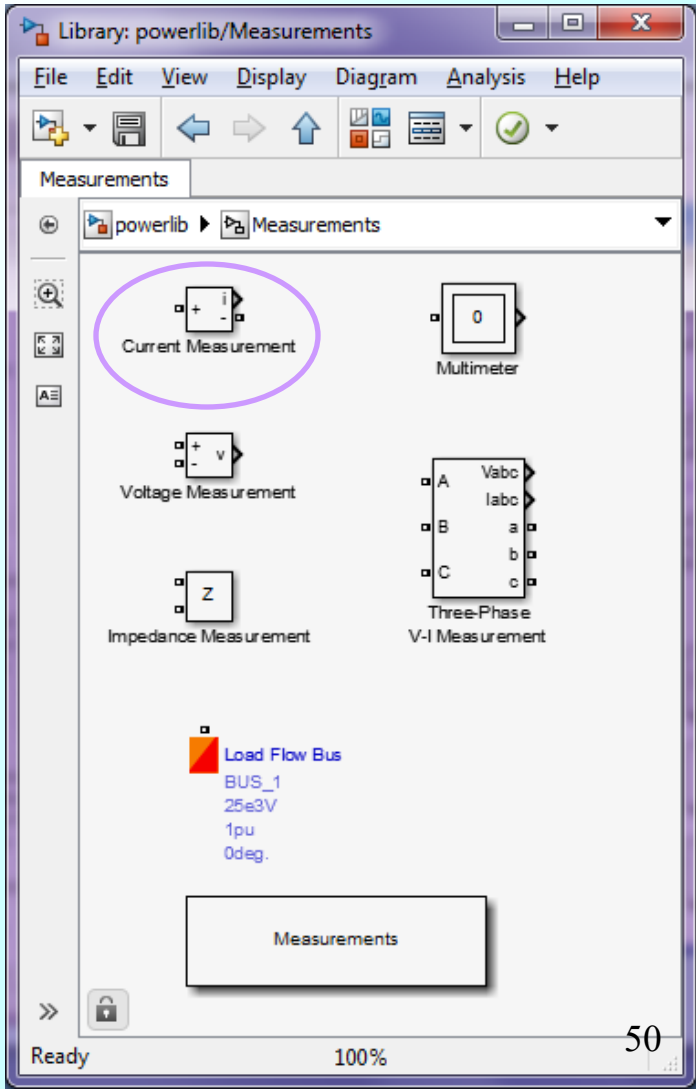


Како се мери напон?

Simscape > Electrical

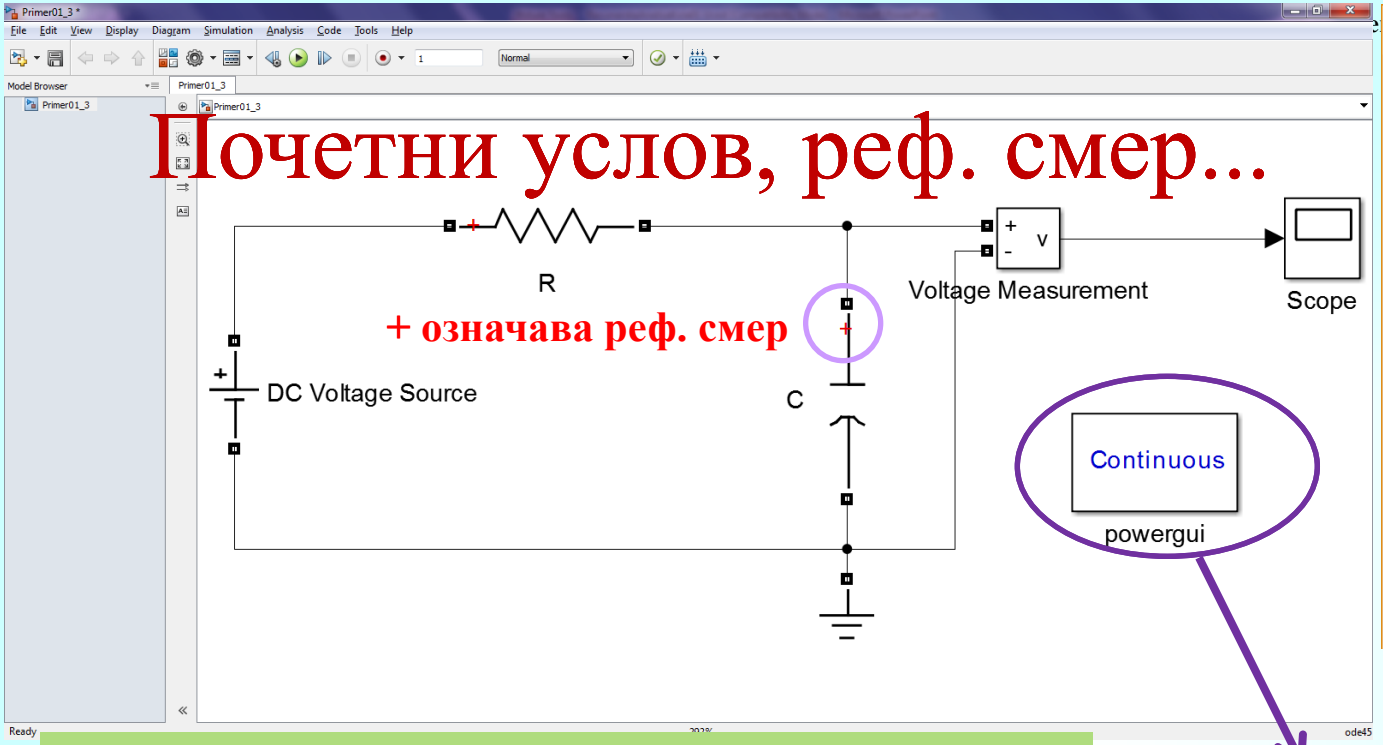
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке





Simscape > Electrical

Почетни услов, реф. смер...



Block Parameters: C

Series RLC Branch (mask) (link)

Implements a series branch of RLC elements.
Use the 'Branch type' parameter to add or remove elem
branch.

Parameters

Branch type: C

Capacitance (F):

1e-6

Set the initial capacitor voltage

Capacitor initial voltage (V):

-10

Measurements None

OK Cancel Help

Плоче кондезатора се разликују!!!

Simscape > Electrical

Block Parameters: powergui

PSB option menu block (mask)

Set simulation type, simulation parameters, and preferences.

Solver Tools Preferences

Steady-State | Initial State

Machine Initialization | Impedance Measurement

FFT Analysis | Use Linear System Analyzer

Hysteresis Design | RLC Line Parameters

Generate Report | Customize SPS blocks

Load Flow

Load flow settings

OK Cancel Help Apply

Powergui Initial States Setting Tool. model: untitled

Initial electrical state values for simulation:

1 'Uc' C = -10 V

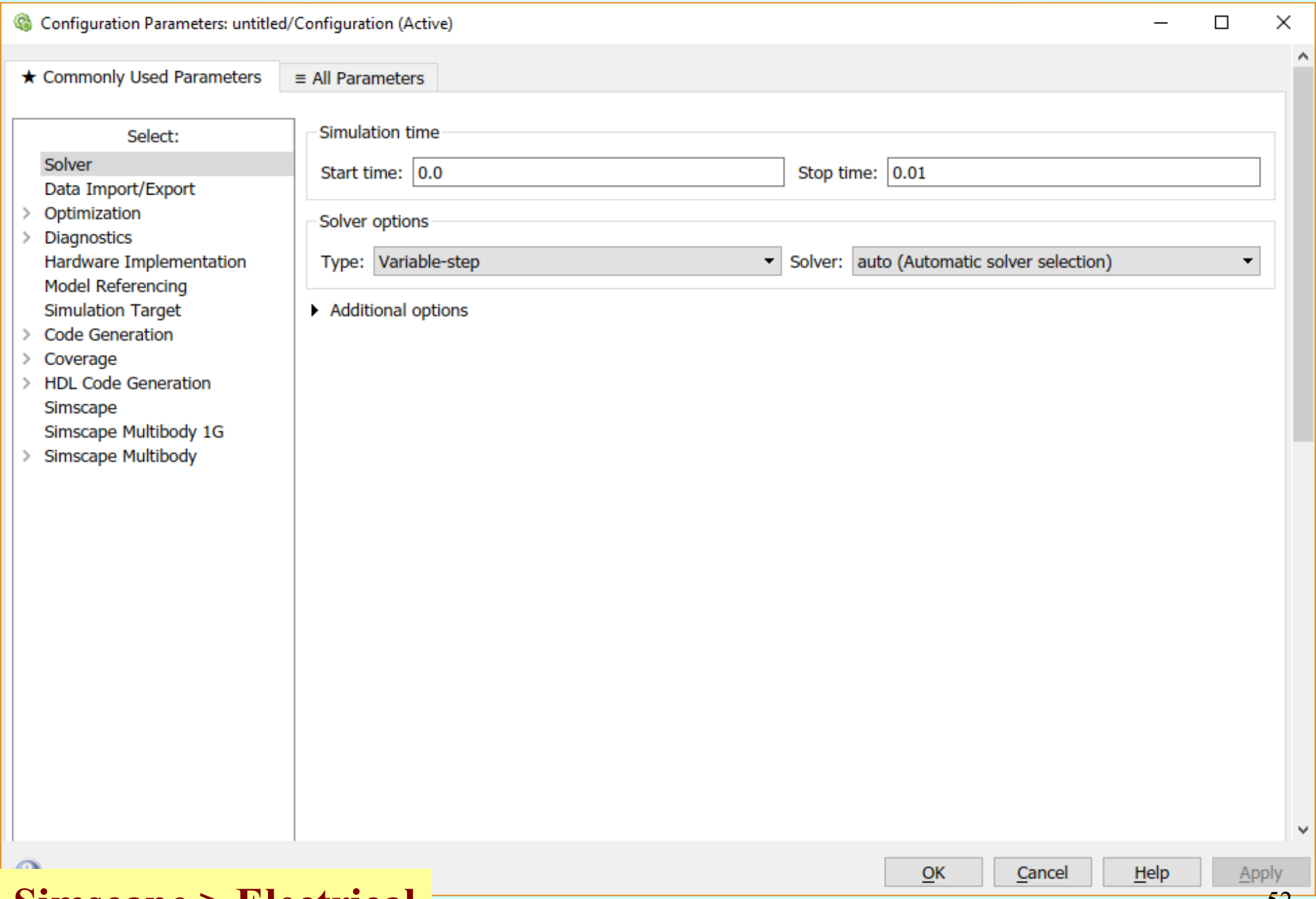
Set selected electric

-10

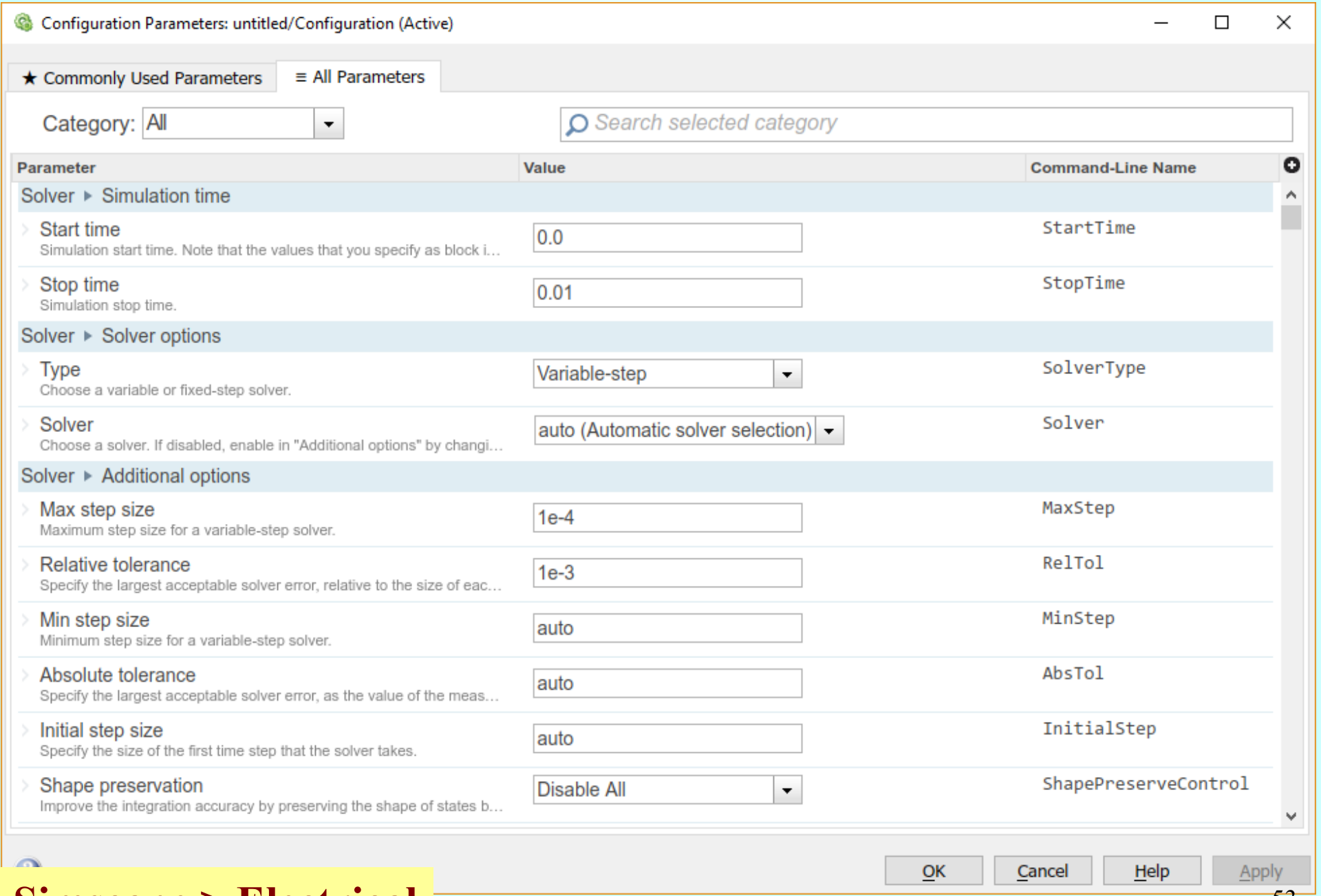
Force initial electrica

To Steady State

To Zero

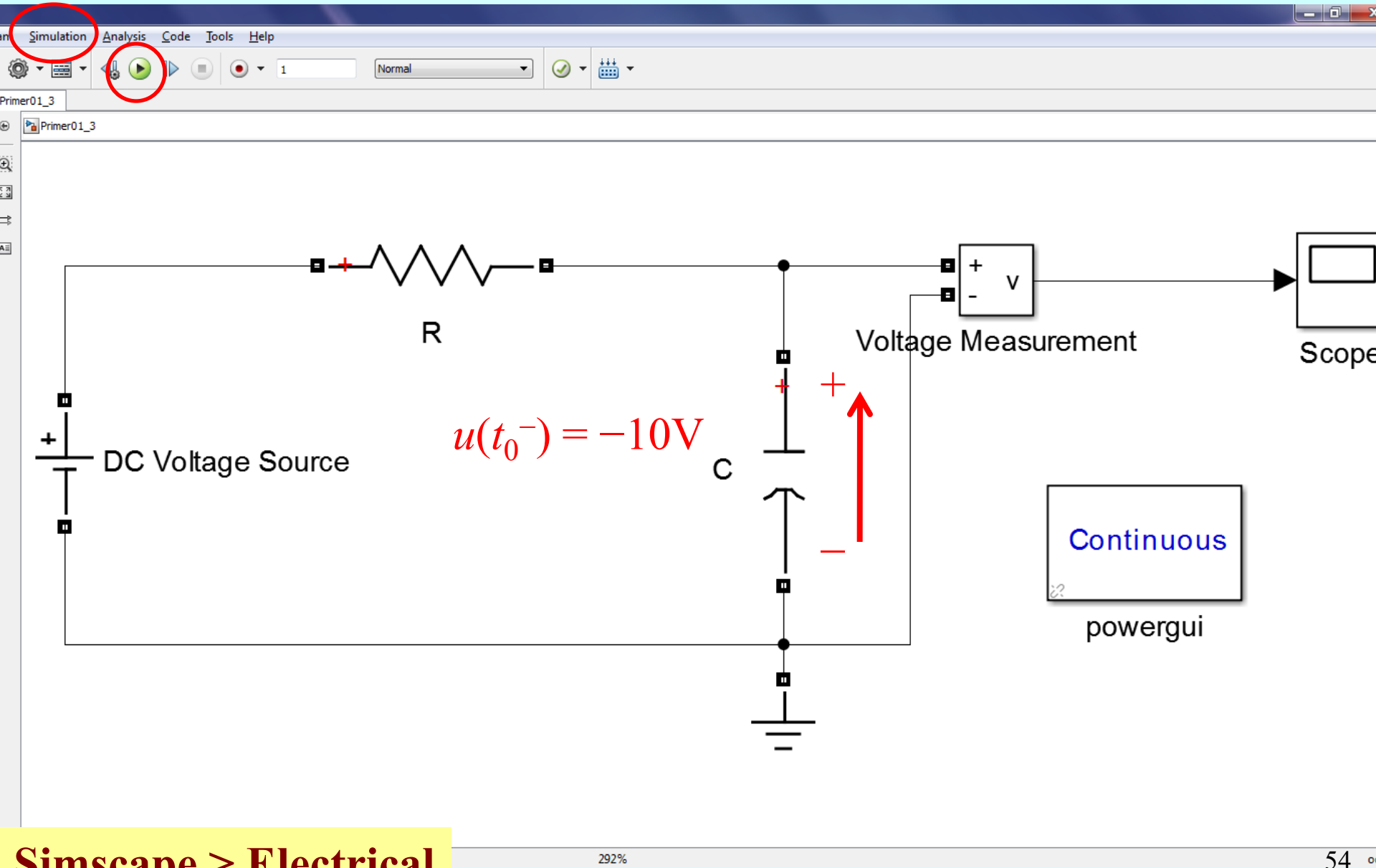


Simscape > Electrical



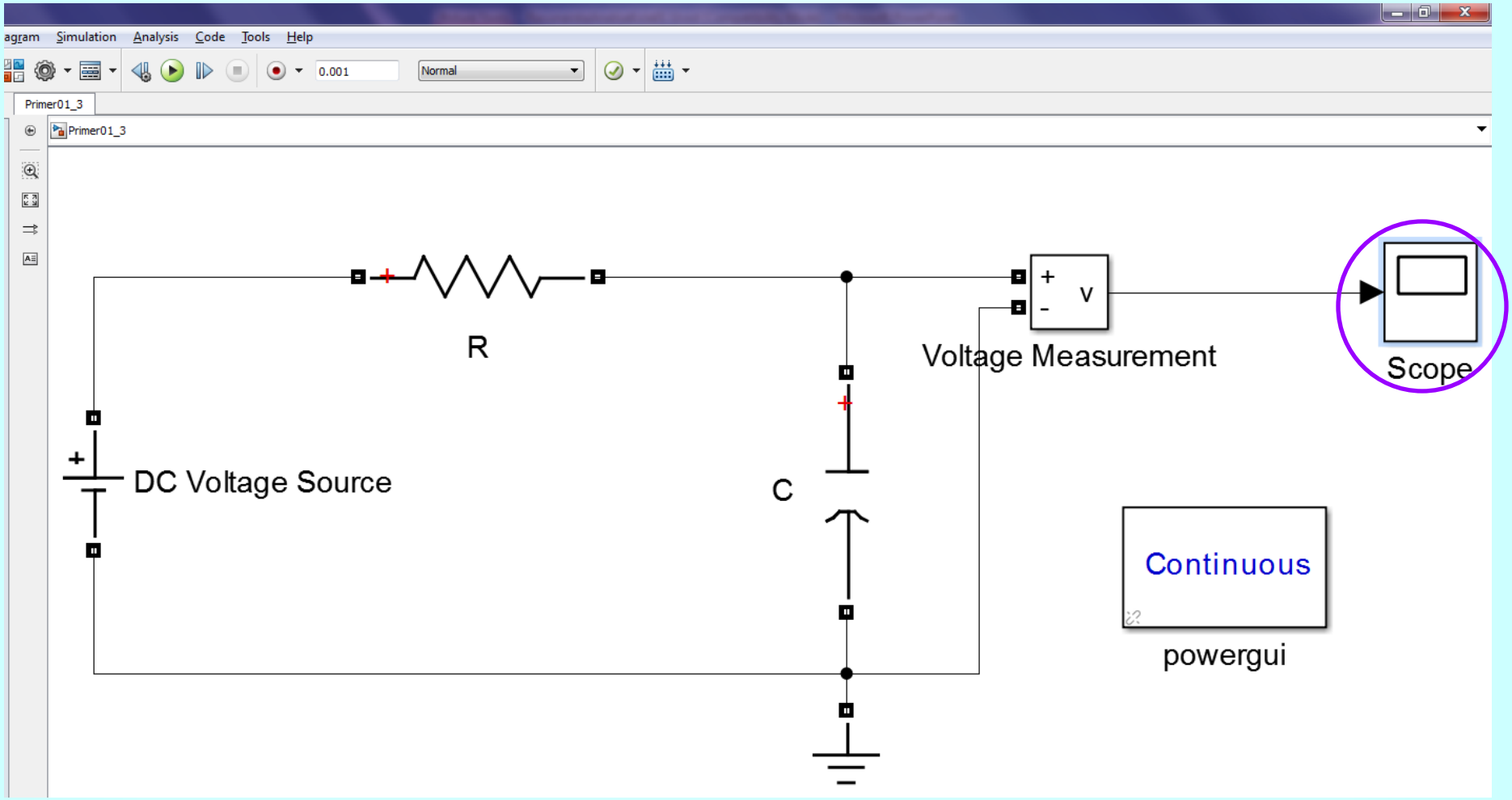
Simscape > Electrical

Покретање симулације...

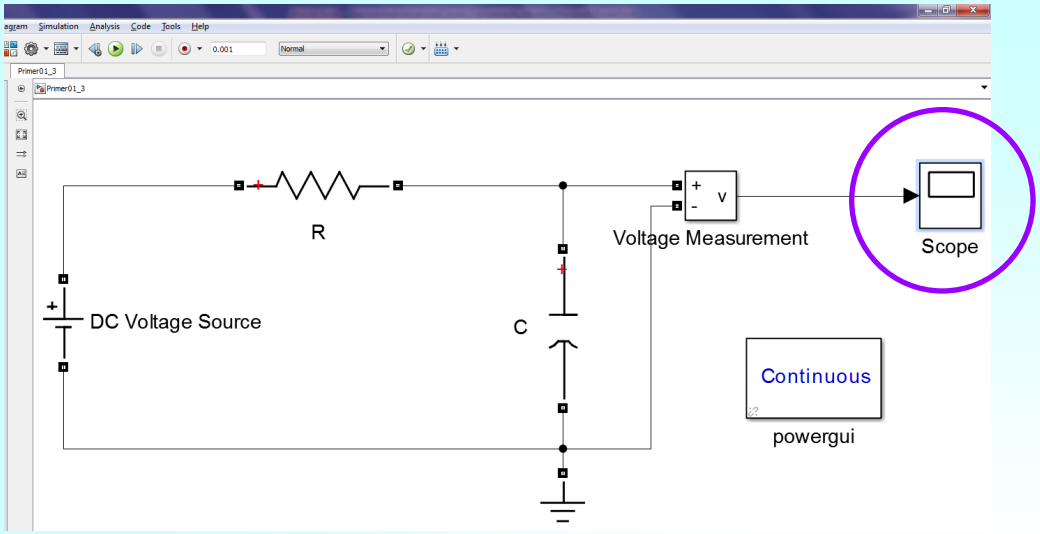


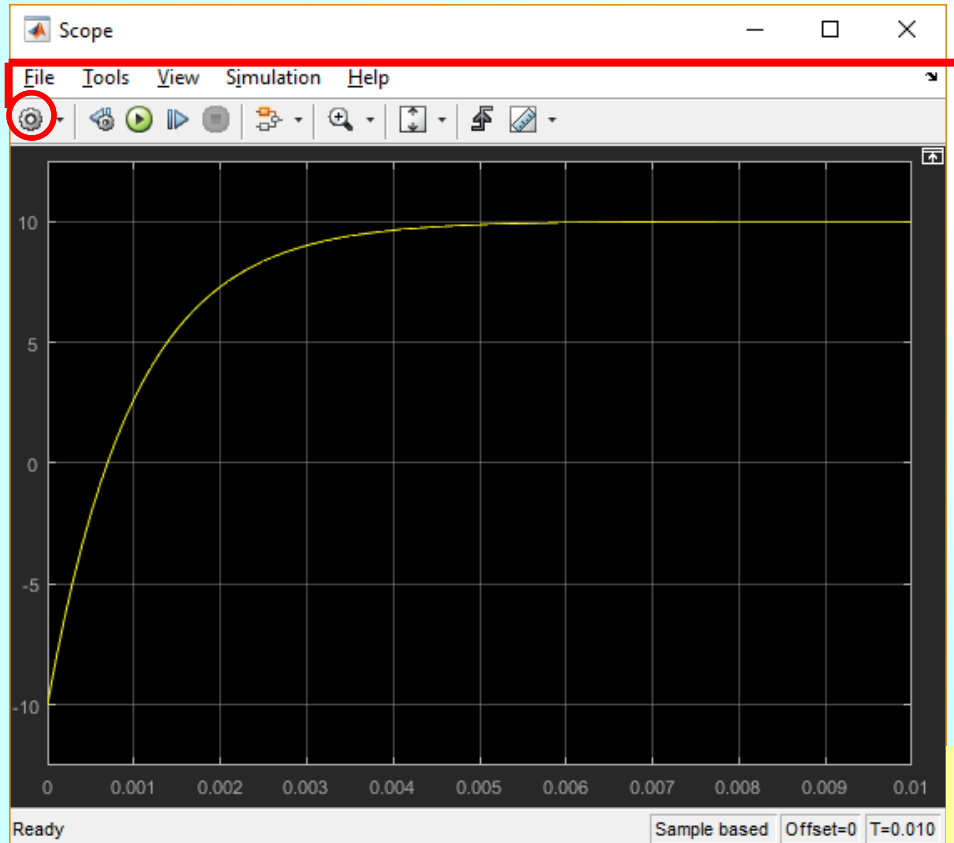
Simscape > Electrical

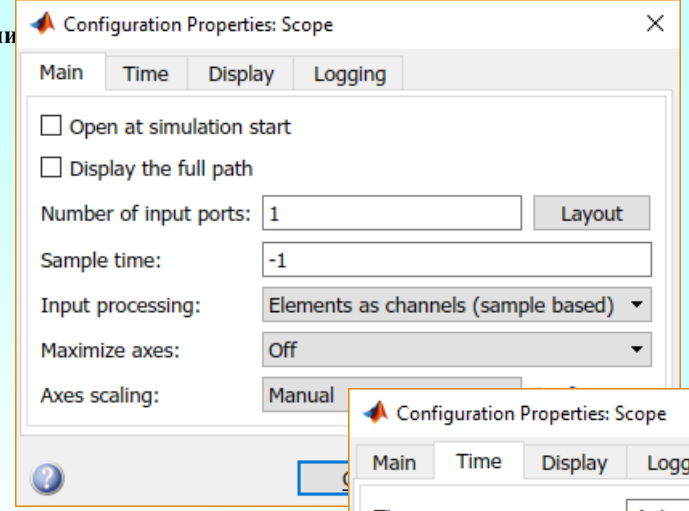
Налажење одзива... Осцилоскоп

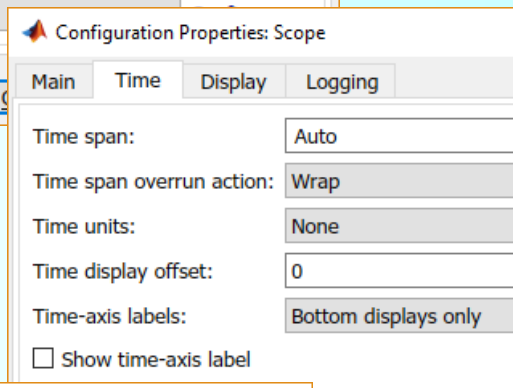


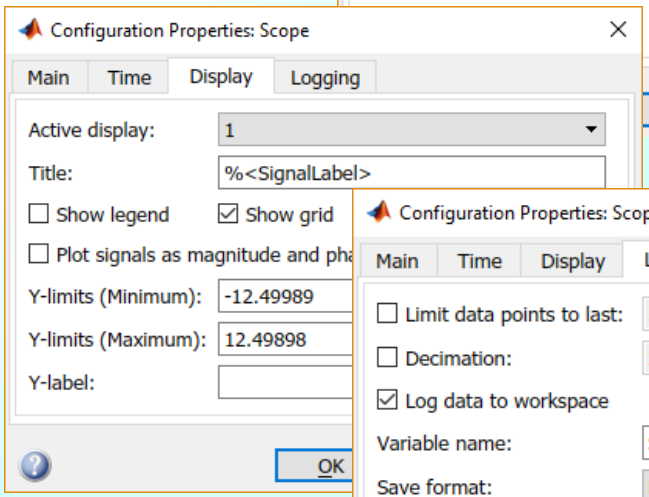
Simscape > Electrical

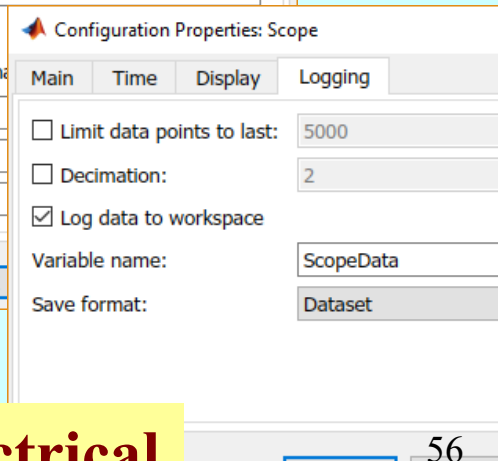












Simscape > Electrical

Configuration Parameters: untitled/Configuration (Active)

★ Commonly Used Parameters | ≡ All Parameters

Category: All

Search selected category

Parameter	Value	Command-Line Name
Solver ▸ Simulation time		
Start time Simulation start time. Note that the values that you specify as block i…	0.0	StartTime
Stop time Simulation stop time.	0.01	StopTime
Solver ▸ Solver options		
Type Choose a variable or fixed-step solver.	Variable-step	SolverType
Solver Choose a solver. If disabled, enable in "Additional options" by changi…	auto (Automatic solver selection)	Solver
Solver ▸ Additional options		
Max step size Maximum step size for a variable-step solver.	1e-4	MaxStep
Relative tolerance Specify the largest acceptable solver error, relative to the size of eac…	1e-3	RelTol
Min step size Minimum step size for a variable-step solver.	auto	MinStep
Absolute tolerance Specify the largest acceptable solver error, as the value of the meas…	auto	AbsTol
Initial step size Specify the size of the first time step that the solver takes.	auto	InitialStep
Shape preservation Improve the integration accuracy by preserving the shape of states b…	Disable All	ShapePreserveControl

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

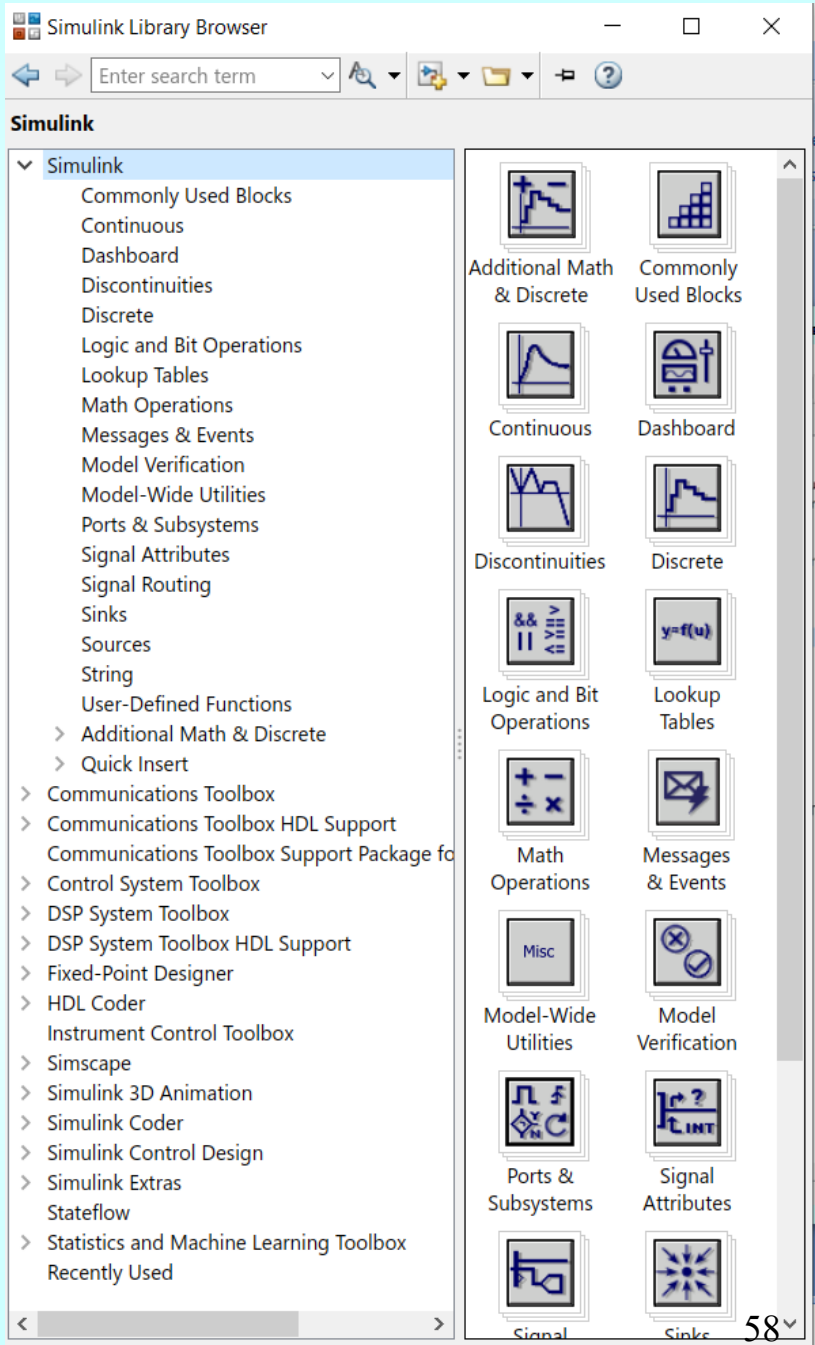
$\tau/10 = 0.1\,\text{ms}$

OK | Cancel | Help | Apply

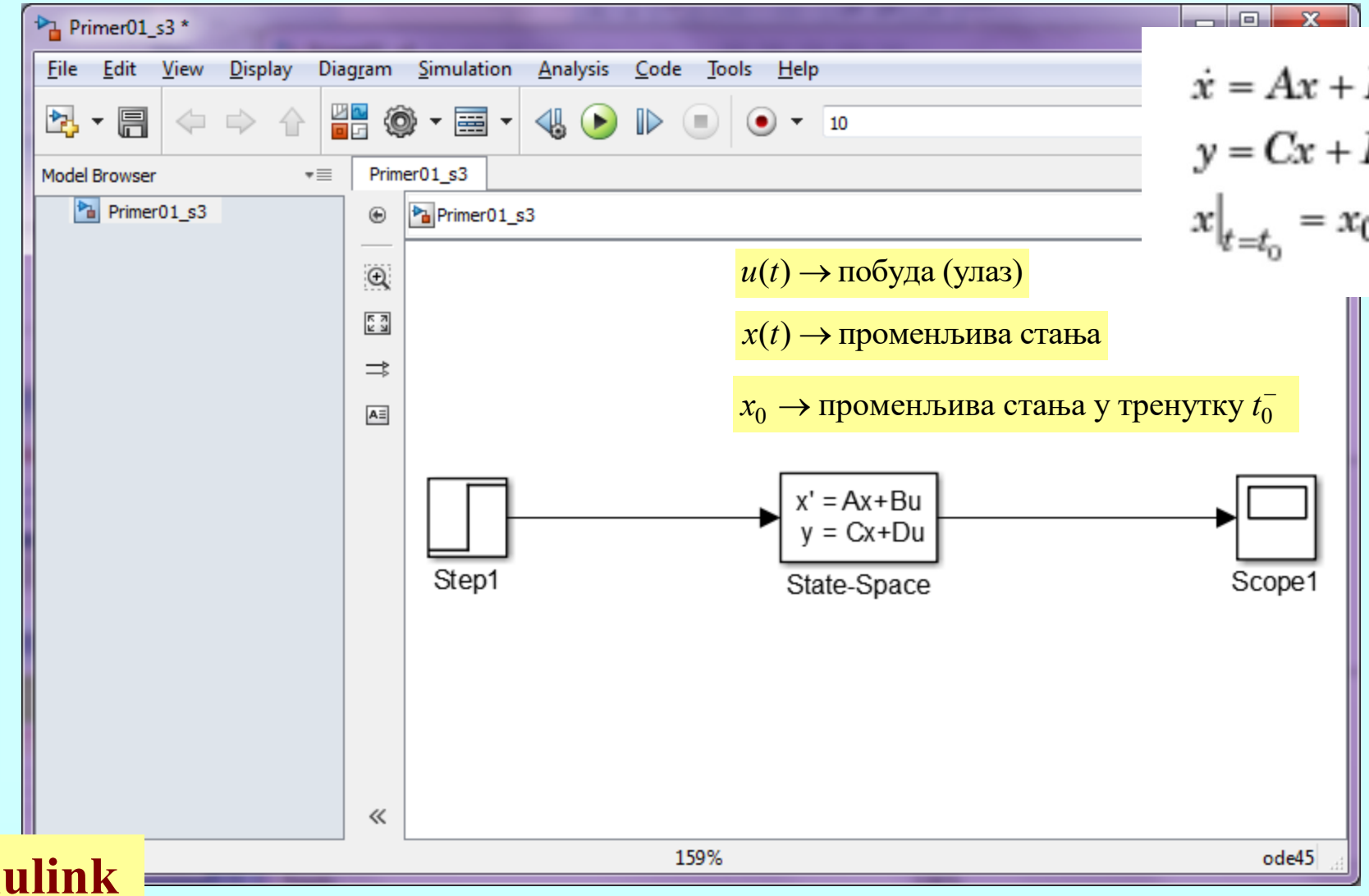
Simscape > Electrical

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

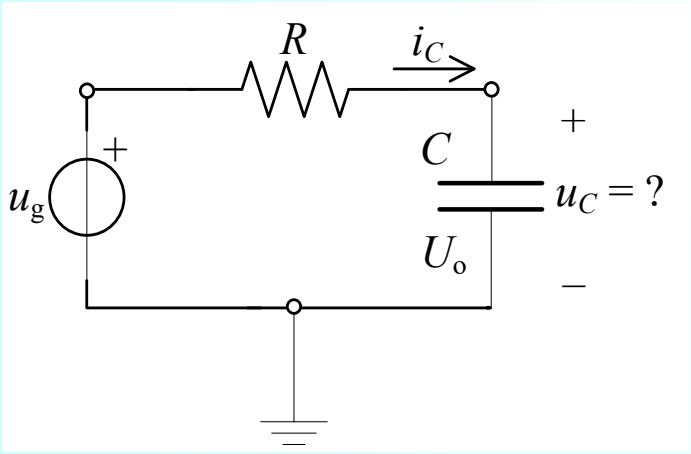


Симулација електричног кола као уопштеног система коришћењем **Simulink**-а



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^-

коло је образовано у тренутку $t_0 = 0$

$$u_g(t) = Ri_C + u_C(t)$$

$$i_C = C\frac{du_C}{dt}$$

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

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

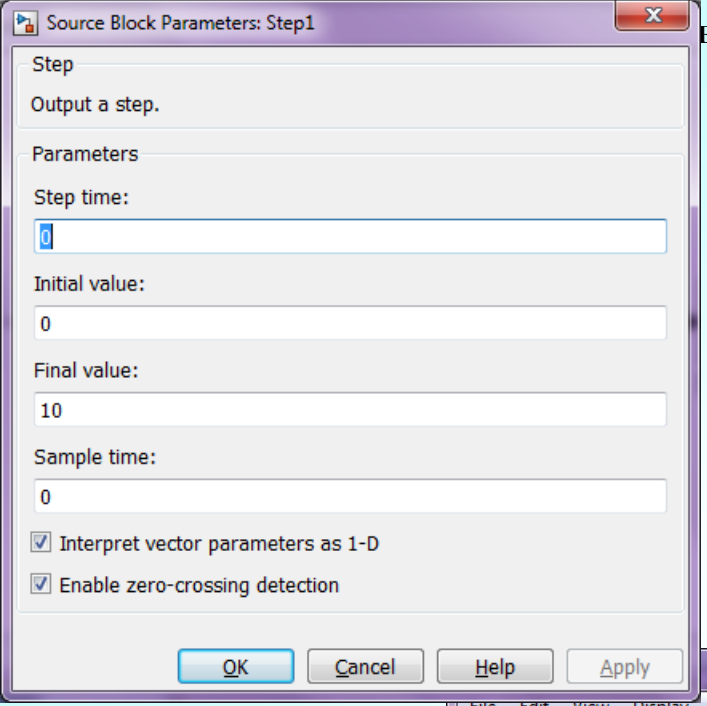
$$R = 1\,\mathrm{k\Omega}$$
$$C = 1\,\mu\mathrm{F}$$
$$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$

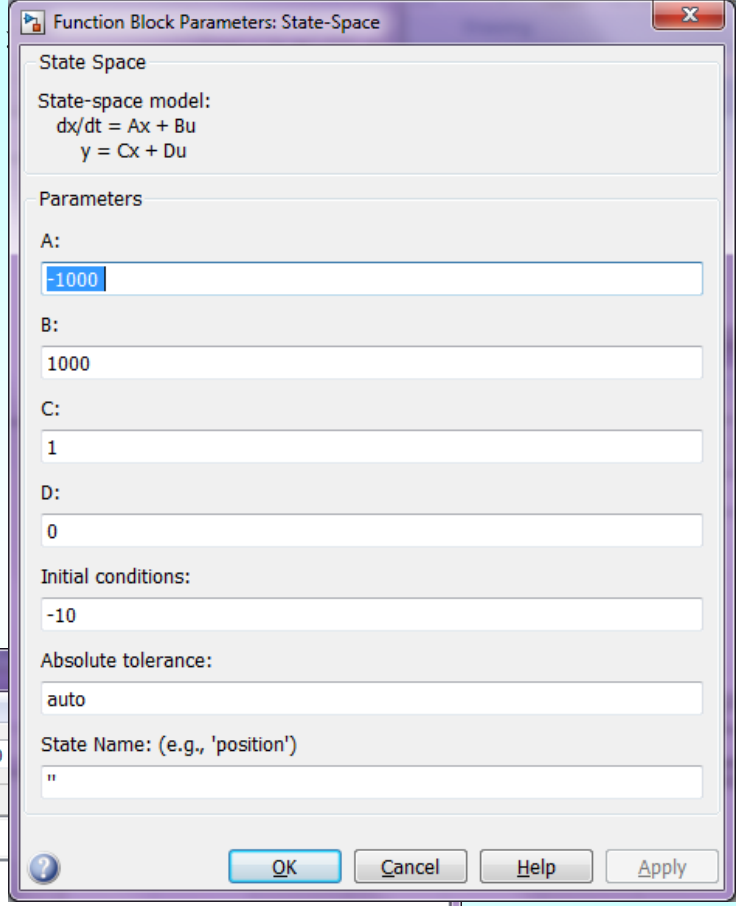
$$\frac{du_C(t)}{dt} = \frac{i_C}{C} = \frac{u_g(t) - u_C(t)}{RC} = -\frac{u_C(t)}{RC} + \frac{u_g(t)}{RC}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$

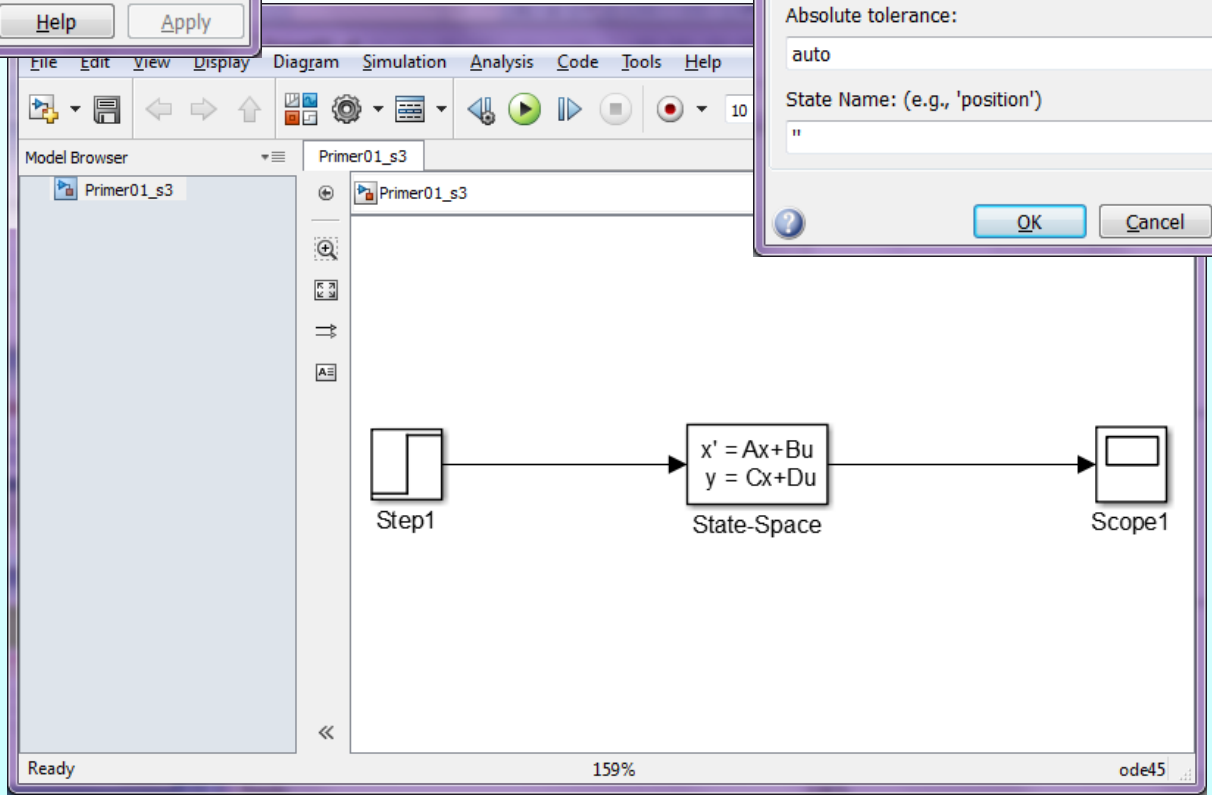
$$\frac{du_C(t)}{dt} = Au_C(t) + Bu_g(t) \Rightarrow A = -\frac{1}{RC} = -1000, B = 1000$$
$$u_C(t) = Cu_C(t) \Rightarrow C = 1, D = 0$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$

Simulink

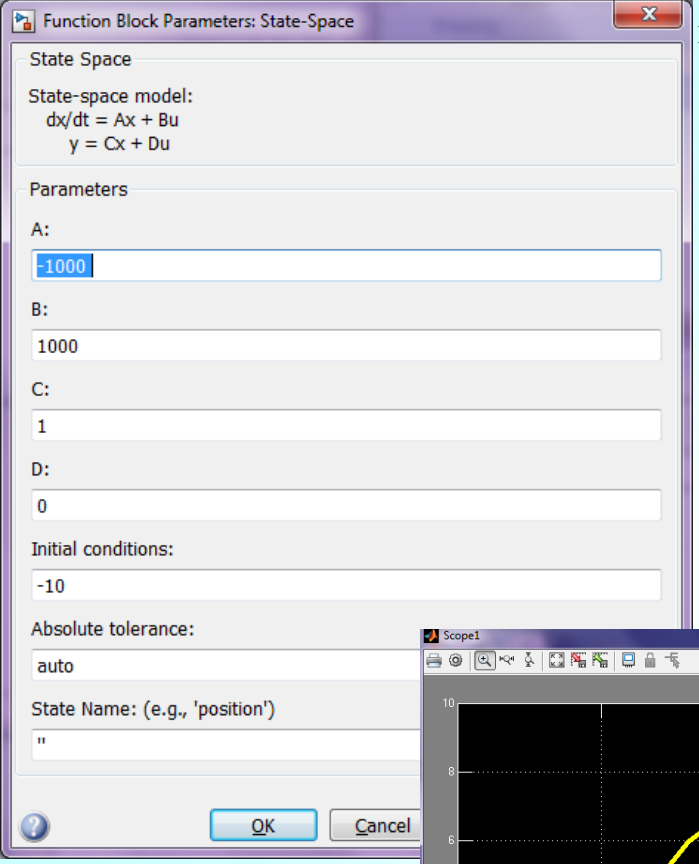
Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

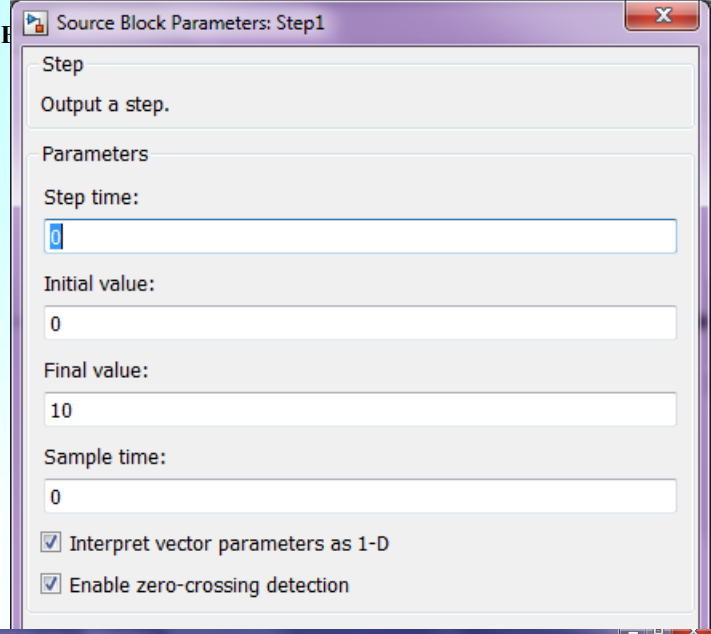


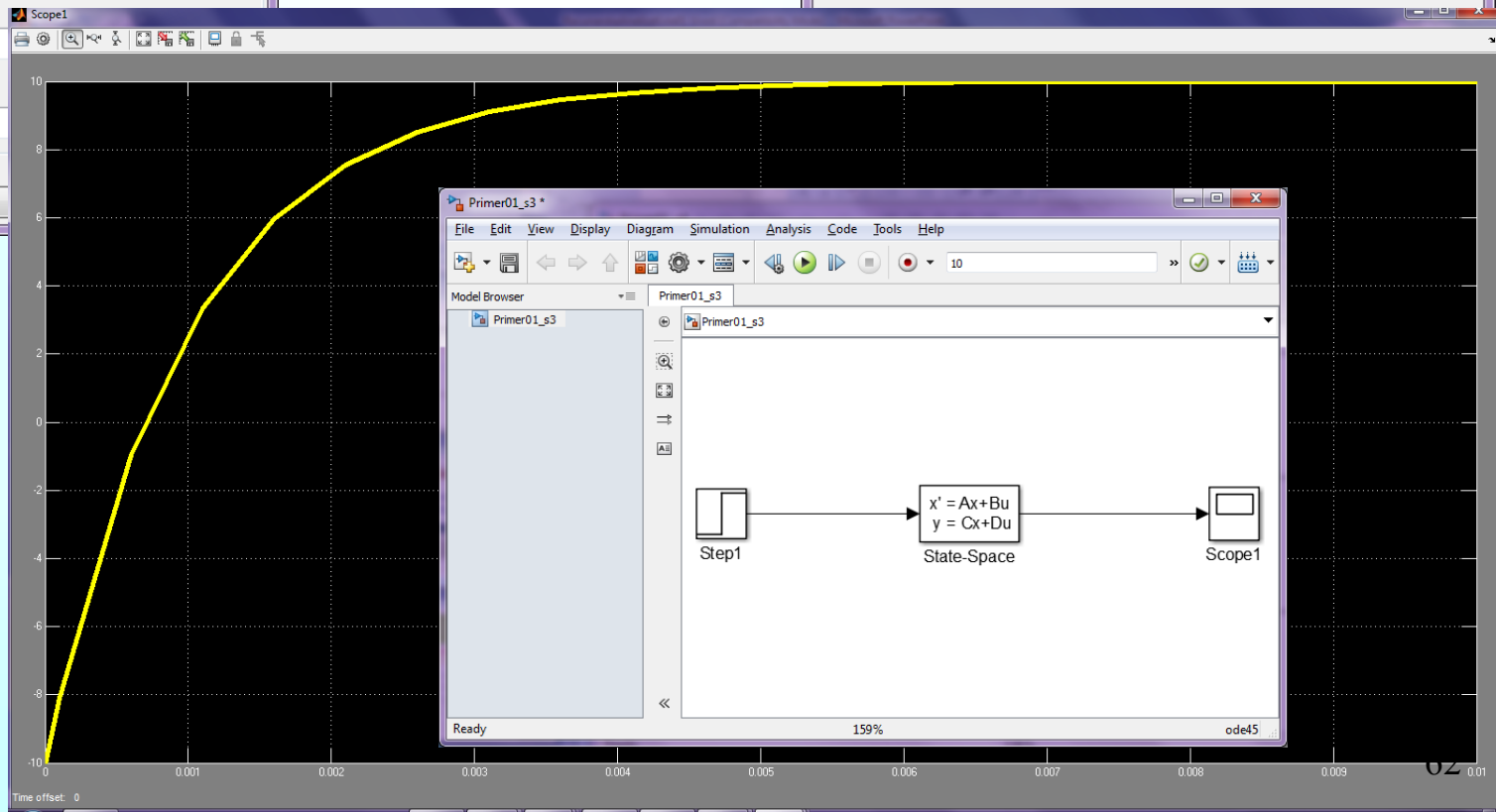




Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

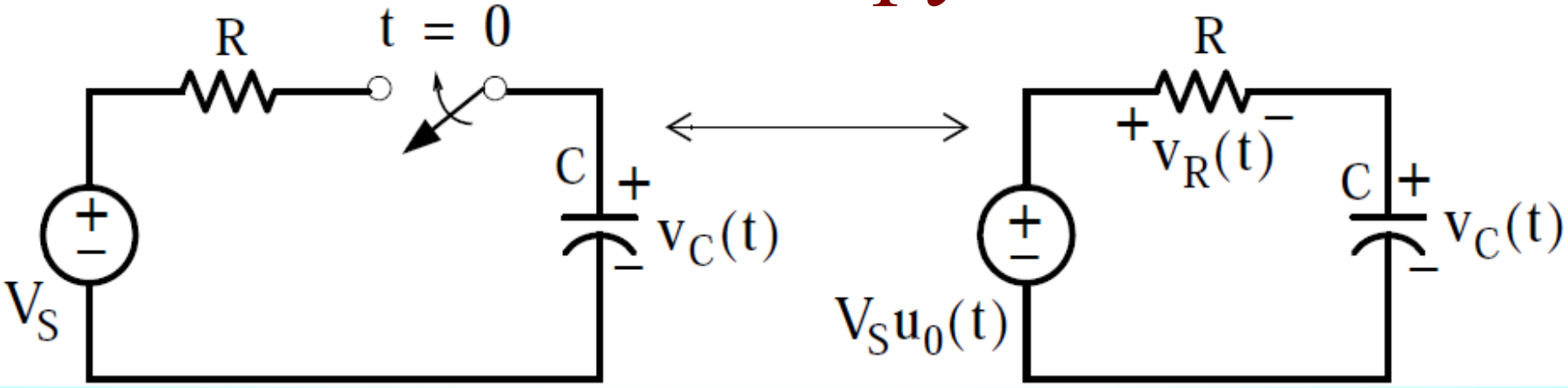






Simulink

Решимо “ручно”



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

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

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

$t > 0$

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

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

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

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

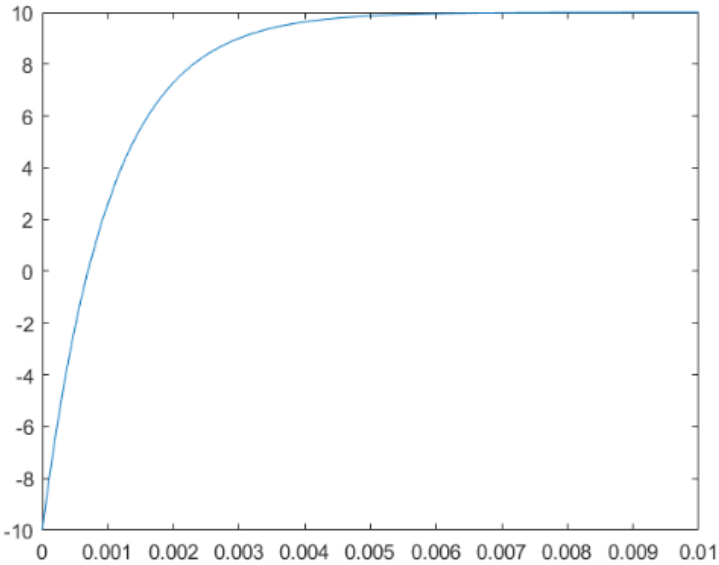
pluto1.m | template1.m | RCKolo_v0.mlx

```
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)];
```

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

```
(%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);
```

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

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

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

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

$$(\%o6)\ [ug=U]$$

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

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

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

$$(\%o8)\ \left[\frac{d}{dt}\,uC=\frac{U-uC}{C\,R}\right]$$

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

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

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

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

```
(%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)$
```